

NAGW-847

**PERSONNEL OCCUPIED WOVEN**

**ENVELOPE ROBOT**

**POWER**

NOVEMBER 30, 1987

A joint project of:

**The Johnson Research Center (UAH)**

**Pace & Waite, Inc.**

and

**Wyle Laboratories**

NASA OFFICE OF SPACE SCIENCE & APPLICATIONS  
INNOVATIVE RESEARCH PROGRAM

STATUS REPORT  
on

PERSONNEL OCCUPIED WOVEN ENVELOPE ROBOT

POWER

NOVEMBER 30, 1987

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## FOREWORD

This study was performed by the University of Alabama in Huntsville for the NASA Office of Space Science and Applications under the NASA Innovative Research Program through Grant NAGW-847. The study was to develop a concept that would provide for external servicing of the Space Station without performing extravehicular activities.(EVA)

The study was to further a concept of using a flexible tunnel to provide shirt sleeve crew access to a pressurized manned work station and provide means to move the work station to multiple Space Station locations.

The grant for this study required three written progress reports which were submitted as scheduled and a final report to be submitted at the end of the contract. The period of performance was December 1, 1985 to June 30, 1988.

This status report represents a condensation of the previously accomplished work performed by a number of personnel at the University of Alabama in Huntsville at Wyle Laboratories and at Pace and Waite, Inc. both of Huntsville, AL.

The principal investigator wishes to recognize the following individuals for their contributions to this work.

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## INTRODUCTION

### BACKGROUND

- UAH Proposed 3 Year Innovative Research Program  
PERSONNEL OCCUPIED WOVEN ENVELOPE ROBOT - POWER

Submitted:	June 27, 1985	\$430K.	Proposed
ATP:	December 1, 1985	\$ 200K.	December 1, 1985
			June 30, 1988

#### PROGRESS REPORTS SUBMITTED:

June 1, 1986  
November 30, 1986  
June 1, 1987

- Project Informally Renamed "Human Occupied SpaceTeleoperator" (HOST)
- Research Activities Performed Primarily By Dr. Wessling  
and UAH Associates  
Subcontractors:

WYLE LABORATORIES - Selected Hardware Analysis/Design  
PACE & WAITE, INC. - System Engineering and Analysis

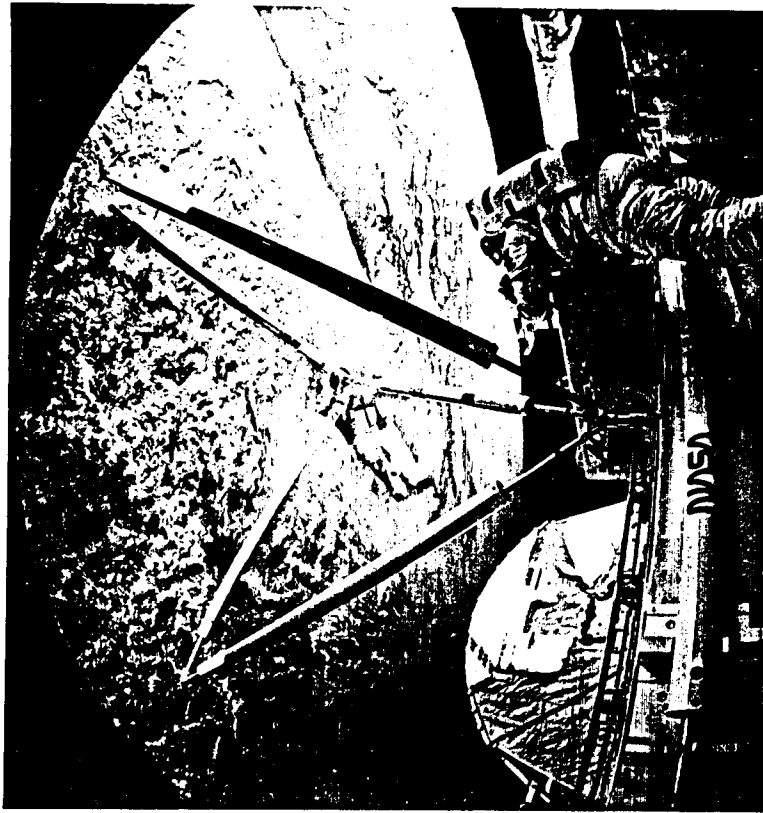
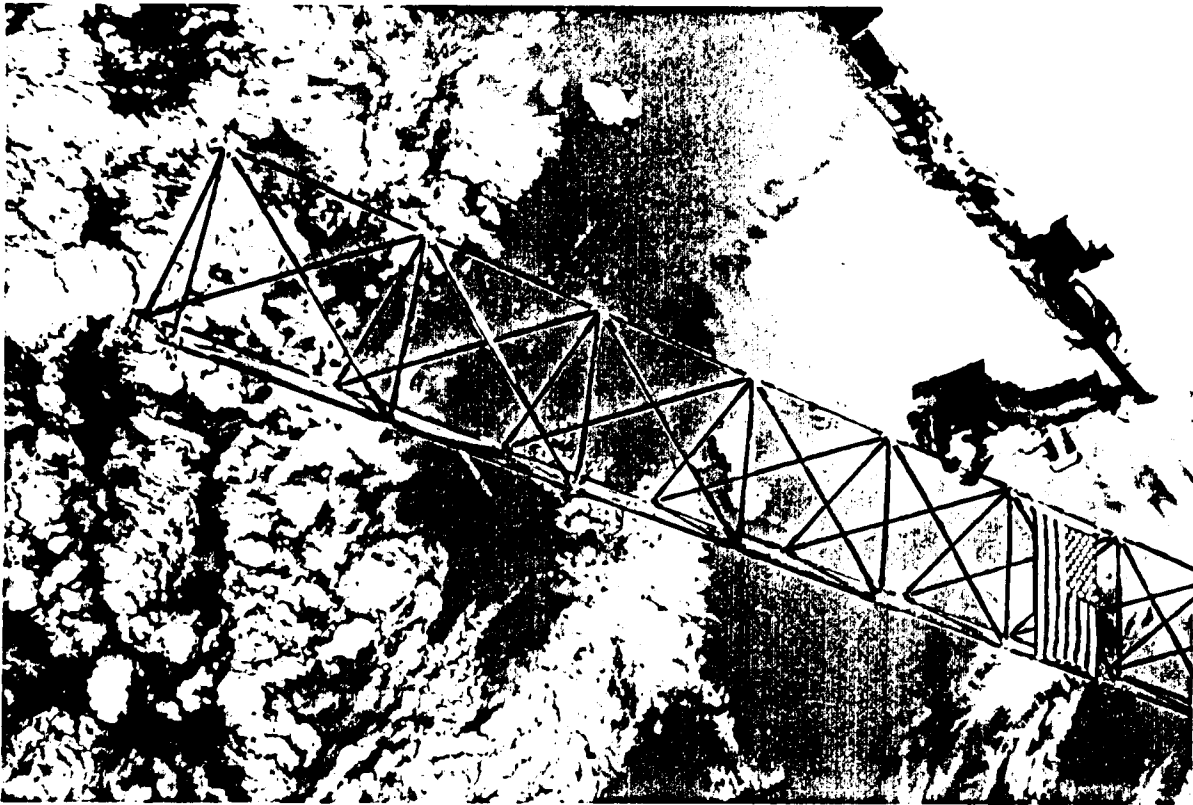
## **OVERVIEW**

### **PROBLEM STATEMENT**

- Space Station Assembly and Subsequent Operations Require Substantial EVA
- Substantial Benefits Of Minimal EVA
  - Reduce Crew Risk
  - Reduce Station Assembly Time
  - Improve Crew Efficiency by Less Fatigue
- Planned Methods Have Substantial Operations Limitations
- Intelligent Space Robots and Smart Teleoperators Require Excessive Development Time for Early Station Activation



OVERVIEW



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EASE-ACCESS Flight Photographs

## **OVERVIEW**

### **RESEARCH GRANT OBJECTIVES**

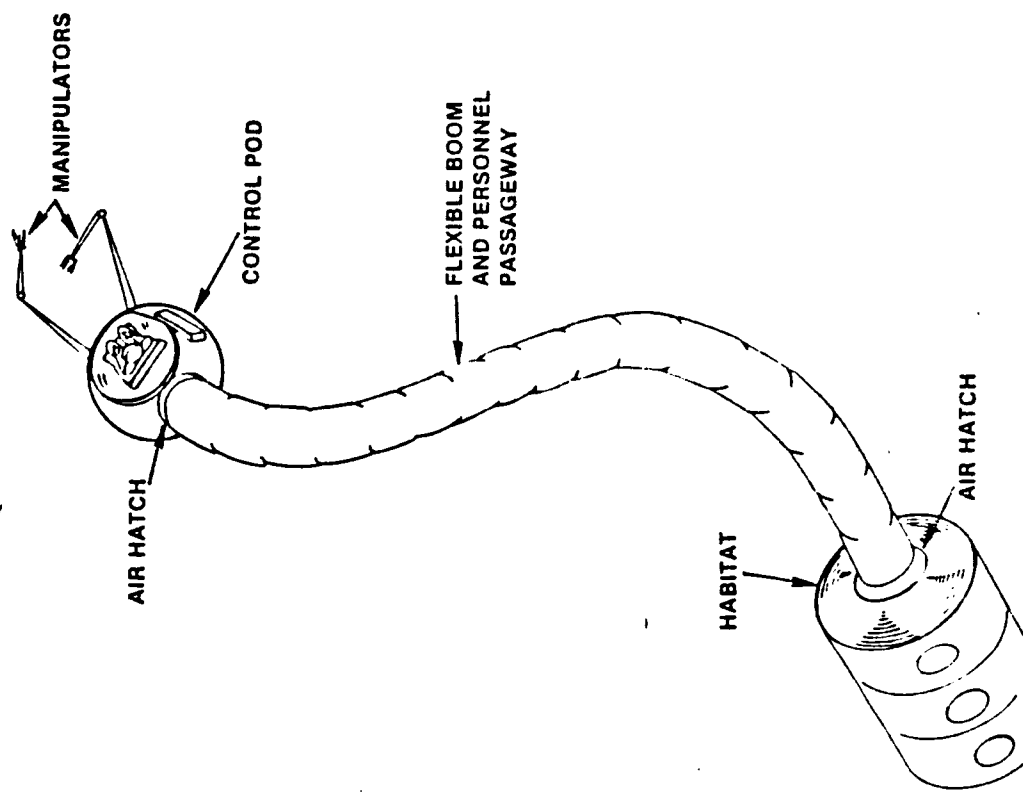
- Devise an Approach to Provide Shirt Sleeve Environment for EVA Tasks w/o EVA Suit
- Determine Opportunity to Advance Use of Fabric Structures for Manned Pressurized Environments
- Give Primary Consideration to Existing Technologies
- Provide Availability Consistent with Station Schedule
- Provide Substantial Operations Improvement Over Current RMS Capabilities
- Perform Conceptual System Design with Multiple Uses and Growth Potential

## **OVERVIEW**

### **CONCEPT EVOLUTION**

- Initially Proposed and Investigated a Flexible Tunnel Approach
  - **Personnel Occupied Woven Envelope Robot - POWER**
- **POWER** Provided Access to Space Station External Work Locations by Use of the Tunnel and a Manned Control Station ( POD )
- Major System Considerations
  - Tunnel Design and Materials Selection
  - Tunnel Control and Reactions
  - Tunnel Atmosphere System and Station Interactions
  - Crew Safety
- System Complexities Led to Approach with Combined Tunnel and Structure Attached to POD
  - Short Flexible Material Tunnel/Crew Hatch
  - Series of Actuator Driven Stewart Tables

## OVERVIEW



PERSONNEL OCCUPIED WOVEN ENVELOPE ROBOT (POWER)

Fig. 2 Proposal Concept of POWER

# OVERVIEW

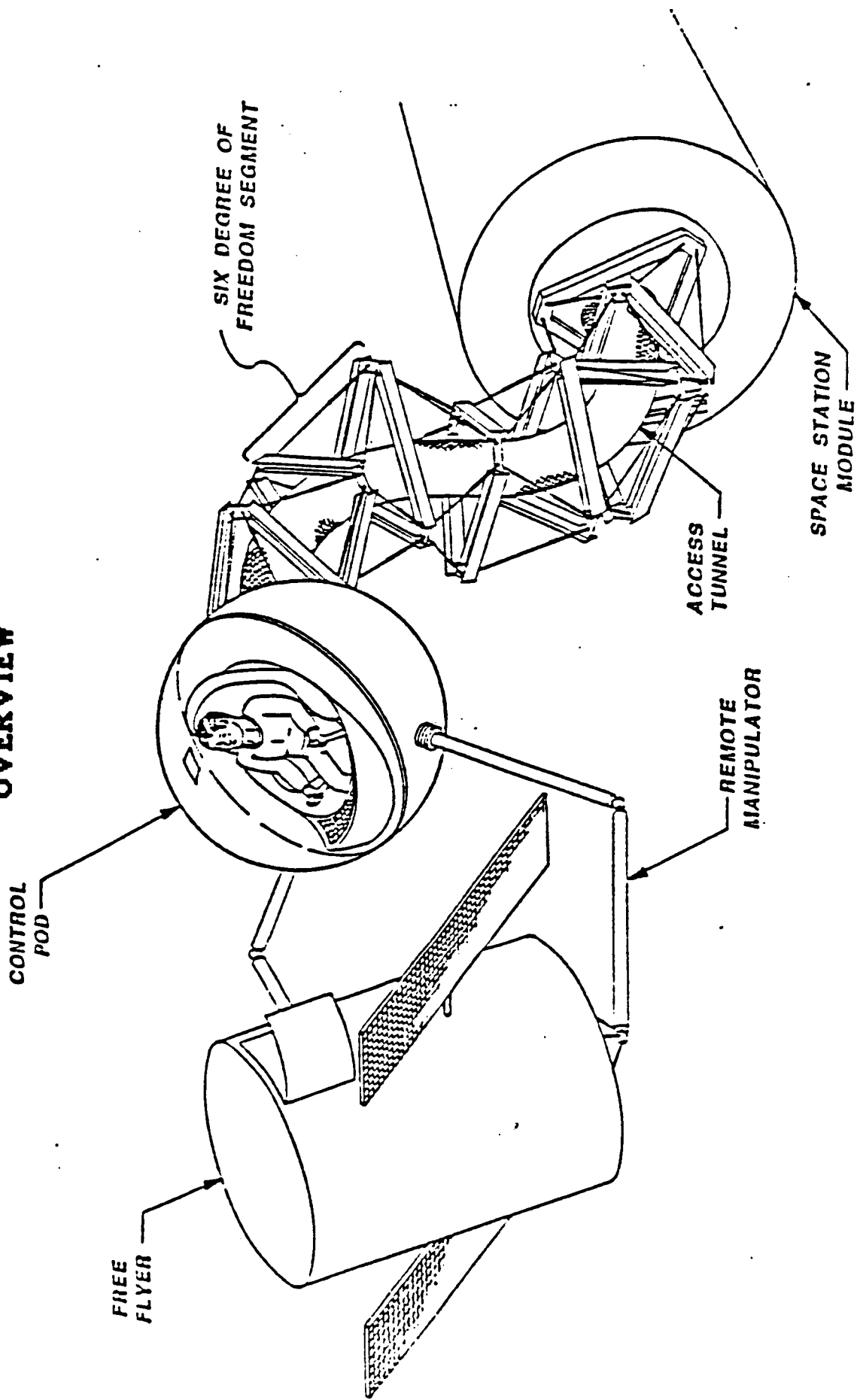


Fig. 3 HOST Long Flexible Tunnel w/ Stewart Tables

## OVERVIEW

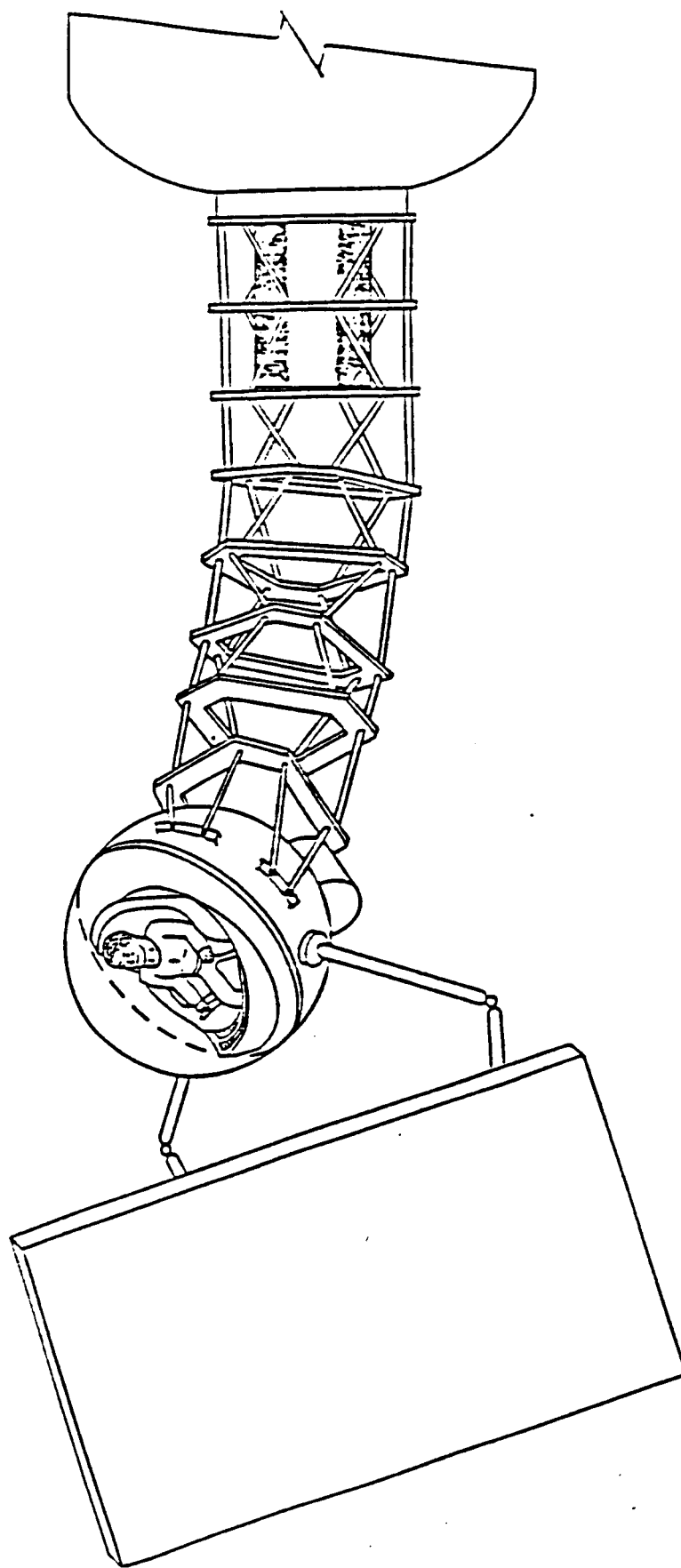


Fig. 4 HOST Short Flexible Tunnel w/ Stewart Tables

## OVERVIEW

### CONCEPT EVOLUTION(cont.)

- Simplified Design and Operations Approach Examined
  - Dock POD Directly to Space Station Resource Node ( Delete Tunnel/Hatch )
  - Attach Base of HOST Support Structure to Station External Structure
- Use of Flexible Tunnel for Crew Transfer Only Still Feasible
  - Use as Moveable Structural Support for POD Not Recommended
- Conceptual Design Based on Direct Access to POD Approach ( No Tunnel )

## **OVERVIEW**

### **MAJOR HOST SYSTEMS - CONCEPTUAL DESIGN APPROACH**

- Structural Attachment Hardware (Base and POD Ends of Exoskeleton Structure)
- Radiator Attachment Structure (Between POD and Exoskeleton Structure)
- Stewart Tables (25) with Electrical Driven Actuators (6 per table)
- Single Person Manned Control Station (POD) with Shirt Sleeve Environment
  - Environmental Control
  - Systems Controls (Including Robot Arms)
  - Communications
  - Emergency Power Supply
  - Caution and Warning System
- POD Mounted Manipulator Arms (2)
- POD Mounted RMS Grapppler Fixture and RMS Type End Effector
- Physical Characteristics
  - Truss Envelope Diameter    7'-9" (Minimum w /High Actuator Stroke Ratio)  
    9' -8" (Maximum w /Test Actuator Stroke Ratio)
  - Length in Orbiter    - 49'-5"
  - Weight    - 7125 Lbs. (Including 25% Contingency)



## OVERVIEW

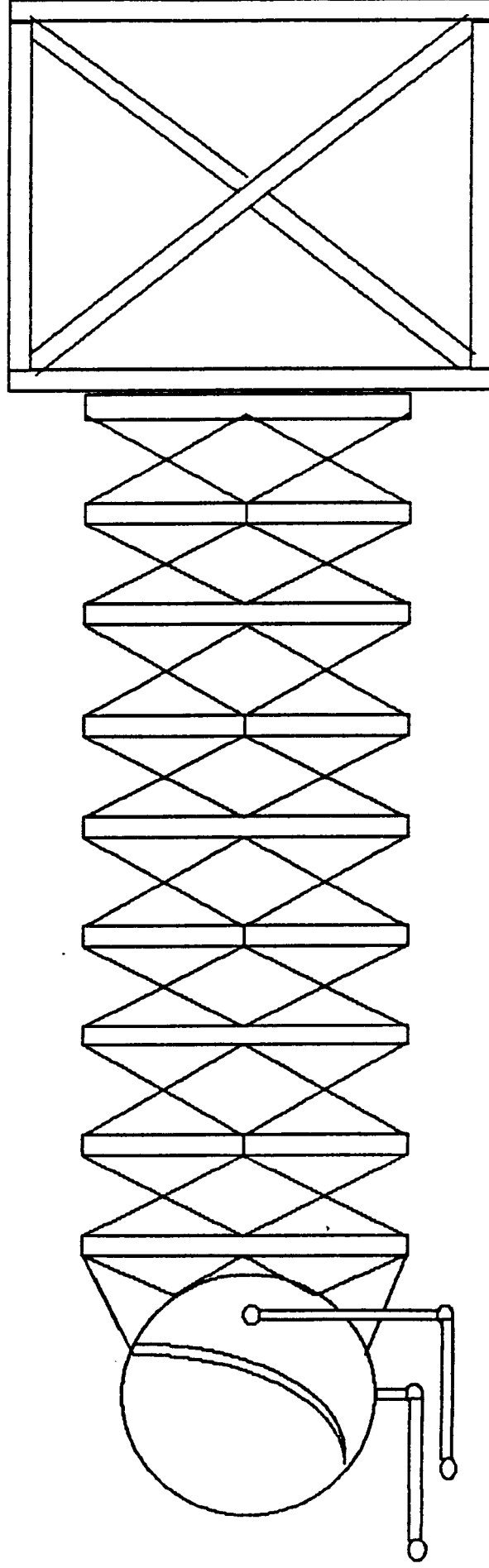


Fig. 5 HOST Conceptual Design (No Tunnel)

## **OVERVIEW**

### **BENEFITS OF A HUMAN OCCUPIED SPACE TELEOPERATOR - HOST SYSTEM**

- Permits Dextrous Space Assembly /Servicing Operations without EVA or Development of Intelligent Robots
- Place Crewperson Within One or Two Meters of Work Station Up to 50 Meters From Station Attach Points (or Shuttle)
  - Provides Operator a 3-Dimension View of Work Without Stereo TV
- One Person Operation from Shirt Sleeve Environment Manned Control Station (POD) with Independent Life Support System
- Equipping POD with Powerful Grippers and Dextrous Manipulators Permits Broad Range of Servicing Tasks
- May Be Used Initially from Space Shuttle and Later Space Station Based for Continuing Station Support
- Eliminates Crew Fatigue Problems Experienced During EASE /ACCESS Shuttle Mission.

## **OVERVIEW**

### **BENEFITS OF THE HOST SYSTEM (cont.)**

- **Uses Developed Technology Avoiding Longer Term Technology Development Such As:**
  - Comprehensive Expert Systems
  - Rapid and Precise Vision Systems
  - Realistic Telepresence
  - Precise Distance Sensors
- **Manned Control Station (POD) Has Large Growth Potential**
  - Add Hardpoint for Compatibility With Other Station Maneuverable Devices for Wider Station Accessibility
  - Evolution Into Manned Space Station Proximity Free Flyer for Inaccessible Locations and Other Transportation Around Station

## APPLICATIONS

- Orbiter Docking to Space Station
  - Flexible Tunnel/Extended Truss Mates Station Docking Port to Orbiter and Provides Crew Transfer via "Jet-Way"
- Space Station Assembly
  - Attached to Space Station Structure
  - Unload SS Components from Shuttle Cargo Bay
  - Perform Module Assembly
  - Potential Additional Station Assembly Use (To Be Investigated)
    - POD Interface w/ Orbiter EVA Hatch (With Truss or W/O Truss - Use RMS)
    - HOST Base Attached to Cargo Bay Structure
    - Use With Truss May Drive Need for POD Remote Operation
    - POD Only Docked to Station Resource Node and Moved by Station RMS
- Satellite Servicing
  - Remote Hazardous Operations
- Space Station Maintenance
  - Inspection
  - Servicing
  - Repair
  - Replacement
- Logistics Support
  - Unloading/ Loading Orbitor Cargo to Resource Node or Unpressurized Storage
  - Local Hardware Relocation / Attachment

## APPLICATIONS

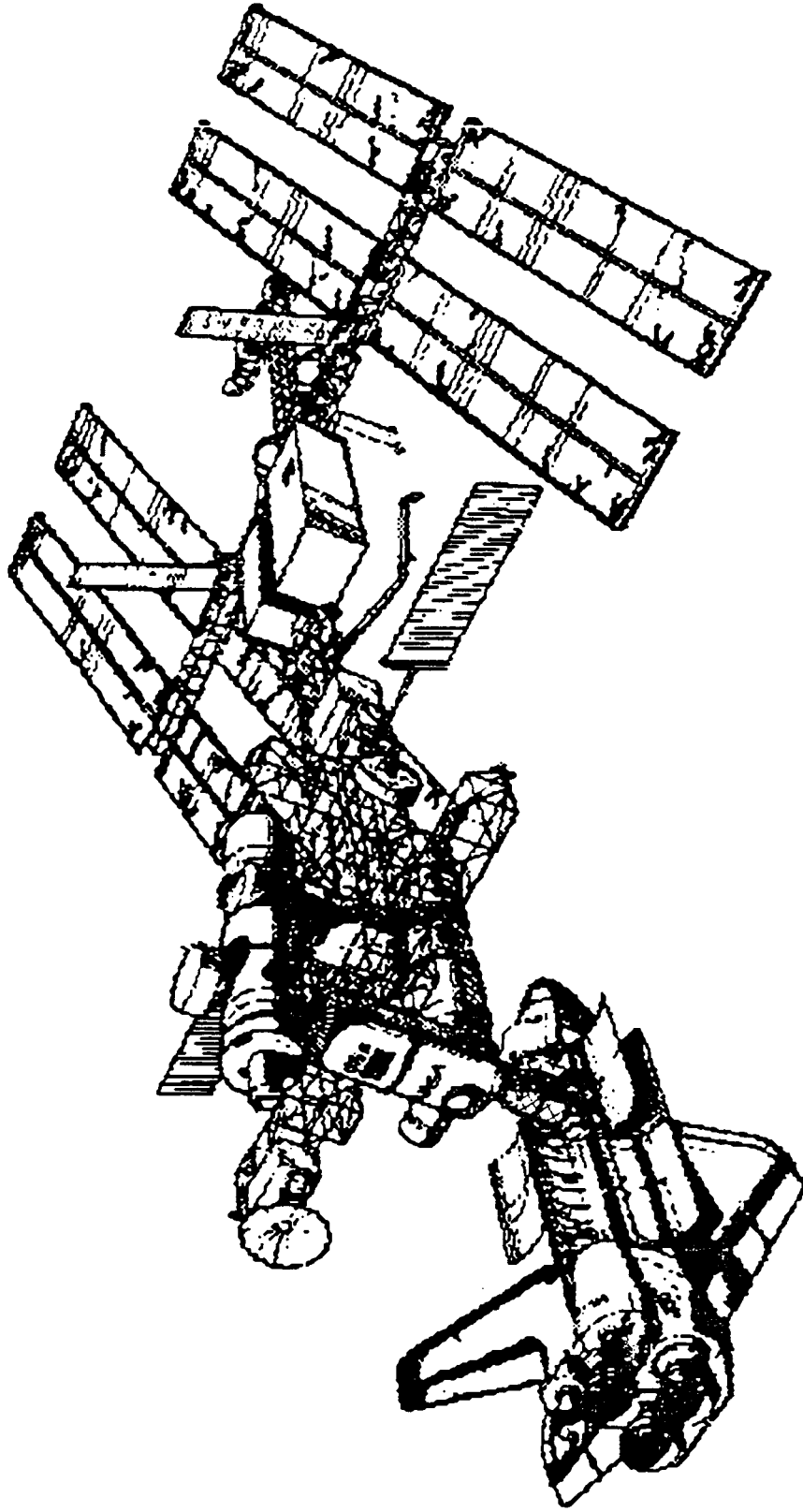
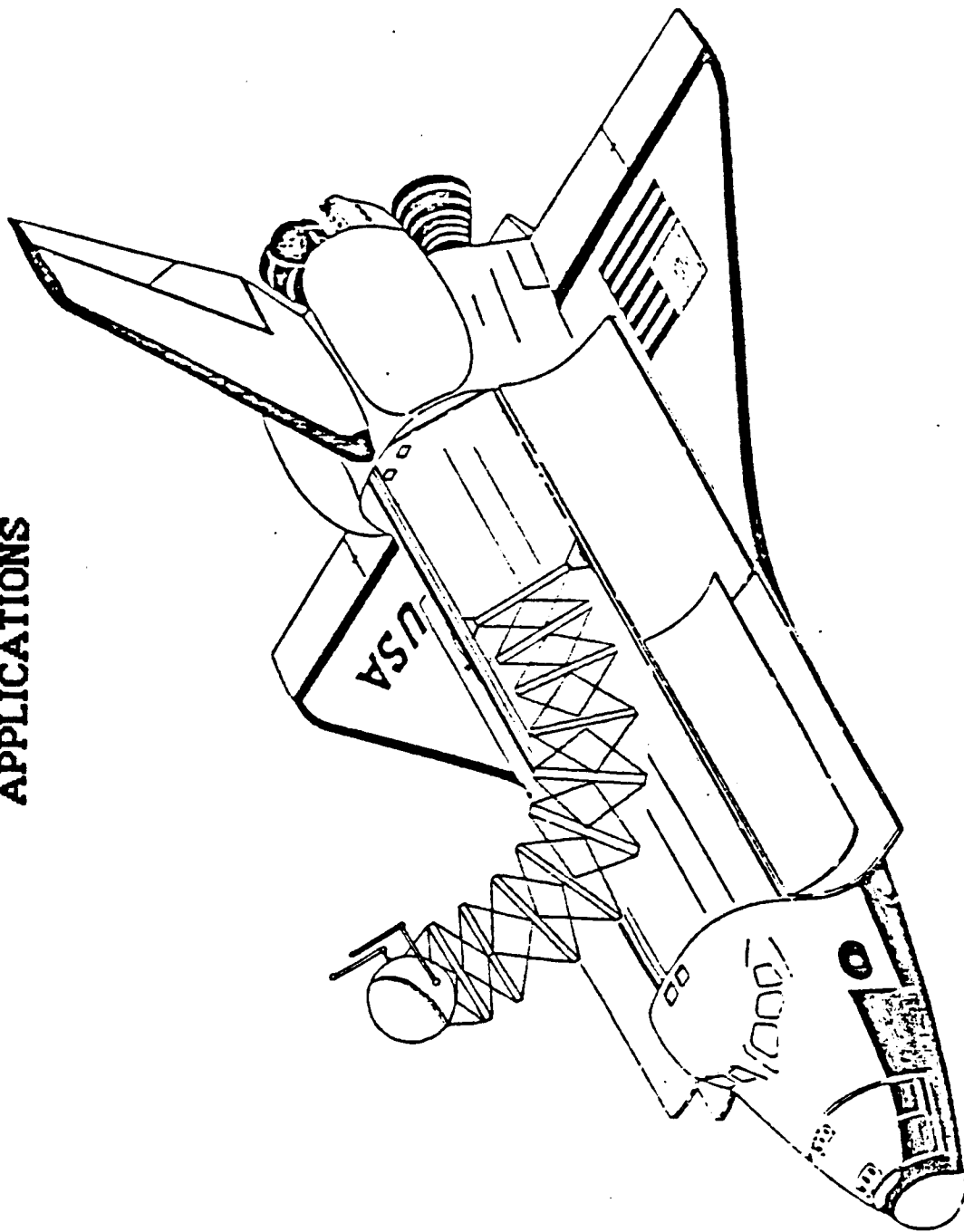


Fig. 6 Orbiter Docking to HOST /Flexible Tunnel

**APPLICATIONS**



**Fig. 7 HOST Deployed From Orbiter**

## APPLICATIONS

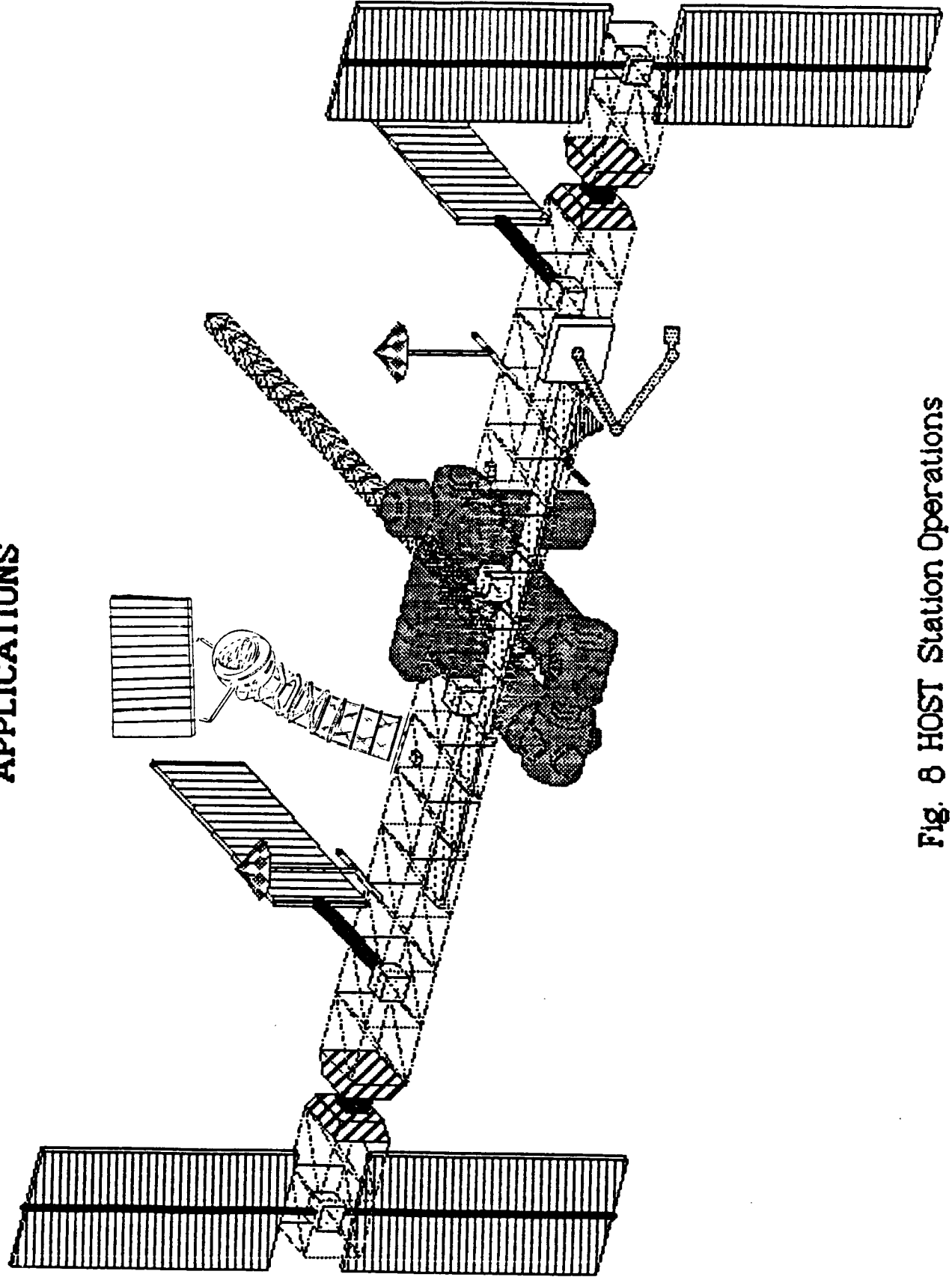


Fig. 8 HOST Station Operations

## APPLICATIONS

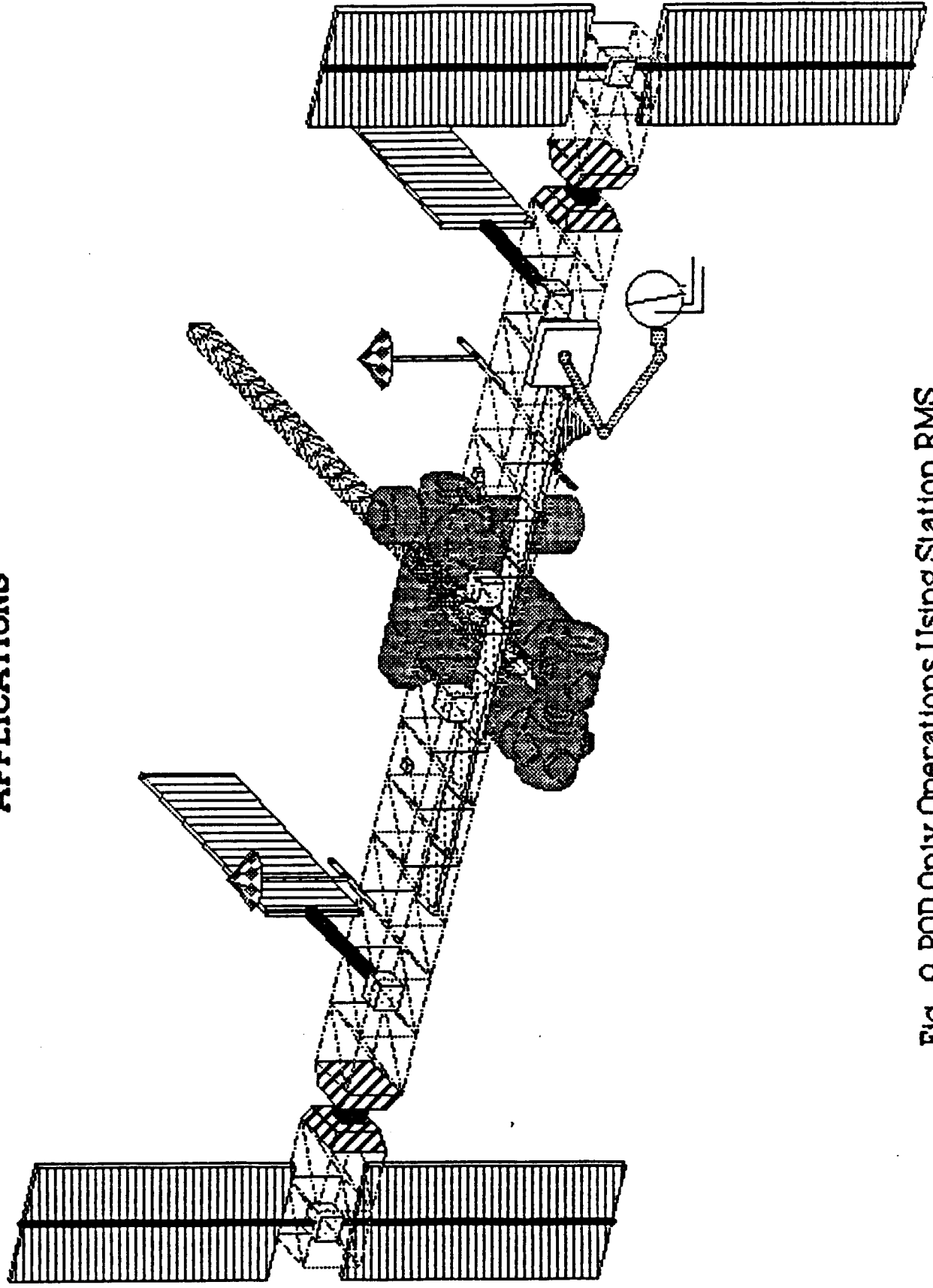


Fig. 9 POD Only Operations Using Station RMS



## **PERFORMANCE AND DESIGN REQUIREMENTS**

- Provide Shirt Sleeve Environment For One Person
- Maneuver a Manned Control Station (POD) Through Six Degrees of Freedom
- Move Up to 50 Meters From Attach Point
- Transport and Attach Heavy Objects with Precision - Causing Minimal Station Disturbances
- Perform Eight Hour Duration Missions
- Perform Delicate Tasks Using Dextrous Manipulator Arms
- Provide Redundant Fail-Safe Recovery Capability

## CONCEPTUAL SYSTEM DESIGN

### SYSTEM DESIGN EVOLUTION

#### FULL LENGTH EXPANDABLE TUNNEL

- Initial Concept
  - Tunnel Provides POD Extension Structure and Crew Access to POD
  - Shirt Sleeve Environment Access Tunnel Between Station Points
  - Crew Hatch Required Between Tunnel and POD Hatch
  - 10 Meters to 50 Meters Expansion
- Preliminary Materials Selection Performed
  - Candidate Based on Goodyear Aerospace Co. Work
  - Prototype for MSFC/MDAC Spacelab Shuttle Tunnel
  - NASA - LRC Test of 1 Person Expandable Airlock
- Multiple Layer Materials Required
  - Pressure Retention
  - Thermal Control
  - External Particle Protection
- Most Attractive Candidate - KEVLAR 49
  - Pressure Bladder - Nylon Fabric, Capran Film, EPT Closed Cell Foam and Aluminum Foil
  - Structural Layer - KEVLAR 49
  - Micrometeoroid Barrier - Polyurethane Foam Laminated to Nylon Fabric
  - Outer Cover - Nylon Fabric Laminated to Layers of Capran Film
    - Serves as Micrometeoroid Bumper and Cover for Surface Maintenance and Thermal Control
- System Complexities Led to Revised Extension Structure
  - Primarily Structure Control Methods

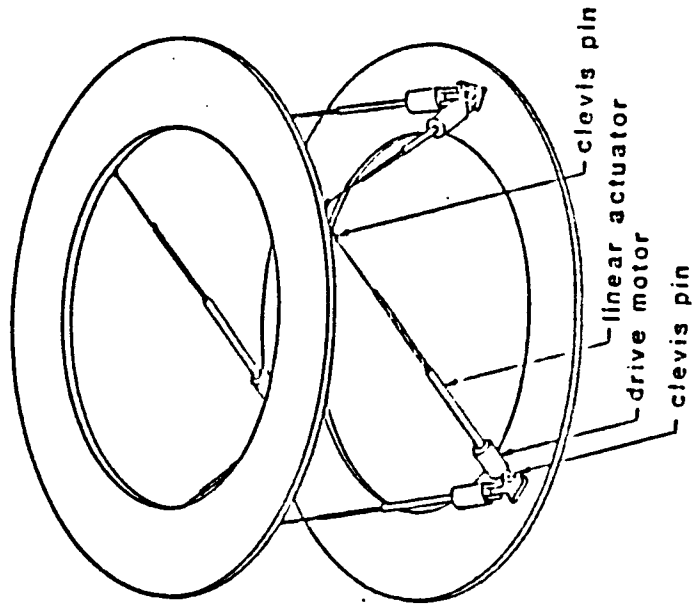
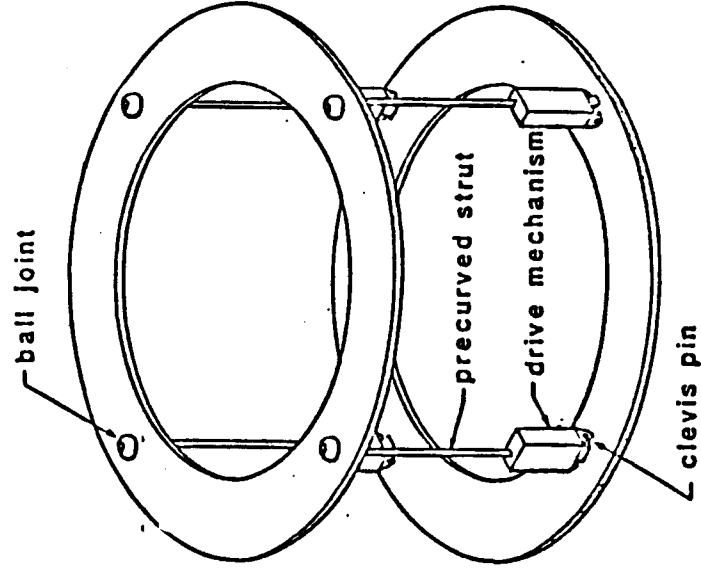
## **CONCEPTUAL SYSTEM DESIGN**

### **SYSTEM DESIGN EVOLUTION STRUCTURE/EXTENSION MECHANISMS**

- Preliminary Studies Examined Several Related Structures/Mechanisms
  - Serpentiuator
  - Astromast
  - Flattened Tube (STEM)
  - Collapsible Tube Mast
  - Extendable Retractable Mast (ERM)
- Fourteen Alternative Drive and Support Mechanisms Examined Including
  - Scissors Jacks
  - Reel & Cable
  - Hydraulic/Pneumatic Jack
- Two Parallel Paths Selected for Follow-on Investigation
  - Four Slit Tube (STEM tube) Longeronns
    - Rejected due to loads and dynamics
  - Mechanical Actuators as Moveable Structural Members

## CONCEPTUAL SYSTEM DESIGN

### SYSTEM DESIGN EVOLUTION STRUCTURE/EXTENSION MECHANISMS (cont.)



Precurved Strut Cantilever Mechanism

Stewart Table

Fig. 10 Extension Mechanism Selection

## CONCEPTUAL SYSTEM DESIGN

### SYSTEM DESIGN EVOLUTION

#### STRUCTURE/EXTENSION MECHANISMS (cont.)

- Electrical Driven Actuators Selected Over Pneumatic or Hydraulic Systems
  - Worm Gear Provides Positive Lockup Feature
  - Avoids Leakage/Contamination and Pressurized Line Management Problems
- For Tunnel Version - Required Tunnel Diameter Drives Table Envelope
  - A 36" Crew Transfer Tunnel (With a 9" Radius for In/Out Mechanism and Clearance Allowance) Requires an Envelope of Approximately 10 ft.-6 inch in Diameter
- For Conceptual System Design (Non-Tunnel Version)
  - Table Envelope Driven by Actuator Design, System Stiffness and Weight Considerations to Meet 50 Meters Extension
  - POD Mates Directly with Station Resource Node (No Tunnel Required)
    - Table Envelope Diameter Reduced to Approximately 7 ft.-9 inches with High Stroke Ratio Actuator of 1.9 (Stroke = 90% of Fixed Length)

## CONCEPTUAL SYSTEM DESIGN

### SYSTEM DESIGN EVOLUTION STRUCTURE/EXTENSION MECHANISMS (cont.)

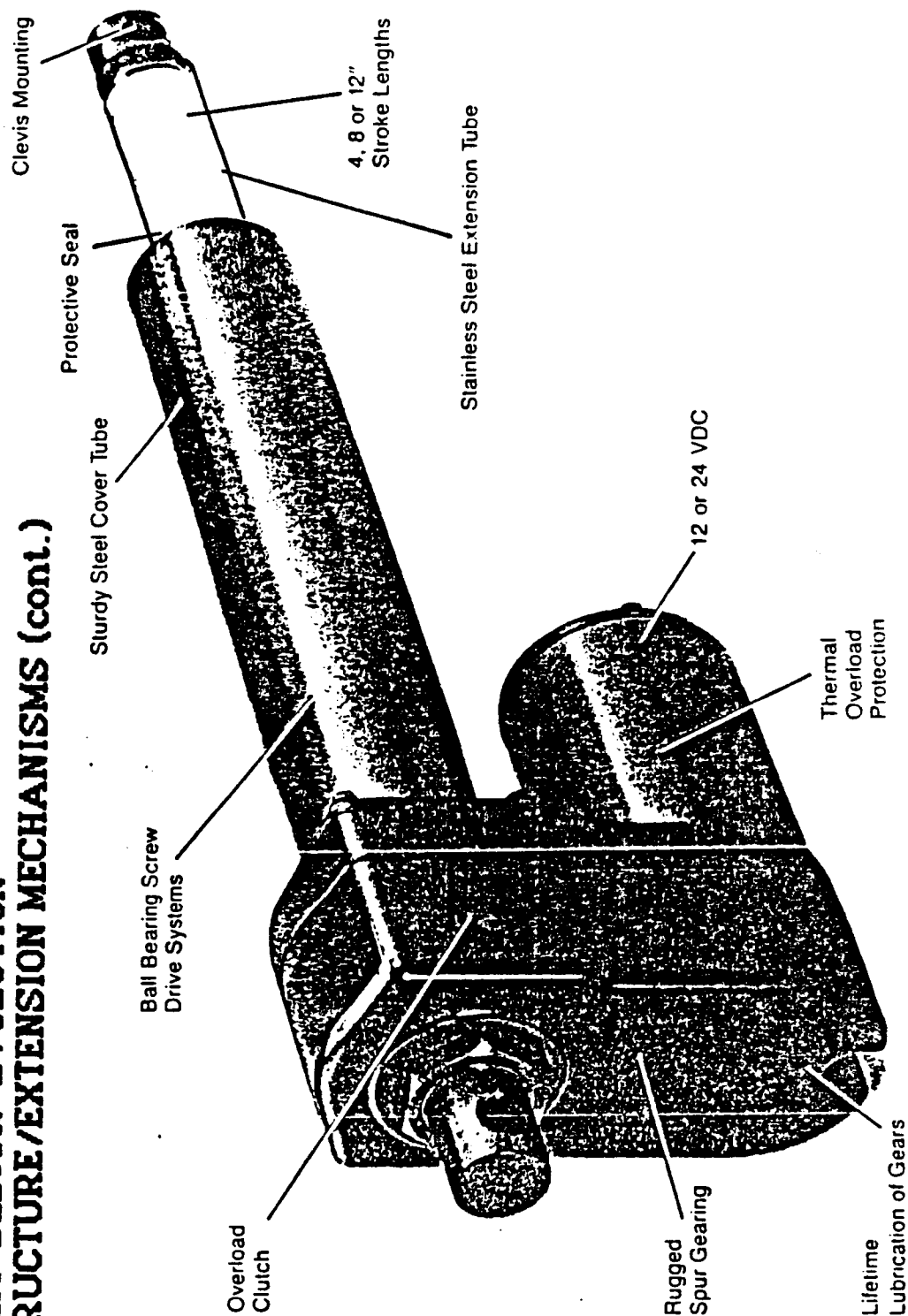


Fig. 11 Ground Test Actuator ( Off- The- Shelf )

## **CONCEPTUAL SYSTEM DESIGN**

### **SYSTEM DESIGN EVOLUTION**

#### **MULTIPLE STEWART TABLES AND SHORT EXPANDABLE INGRESS TUNNEL**

- Ingress Tunnel and Truss Base Attached to Station Resource Node
  - Truss Other End Attaches to POD Radiator Panel Support Structure/POD
- Total Structure Expands From 10 to 50 Meters
  - Compressed Tables and Maximum Tunnel Length - 10 Meters
  - Flexible Tunnel Contracts to 2 Meters
- Crew Hatch Required Between Tunnel and POD
- Residual Tunnel Length May Limit Movements of Initial 2 Meters of Table Structure
- Short Tunnel Reduces System Design /Operations Complexity - Still Requires Tunnel Development, Tunnel Mechanism and Extra Hatch
- Flexible Tunnel Not Pursued-Selected Conceptual Design With No Tunnel

## **CONCEPTUAL SYSTEM DESIGN**

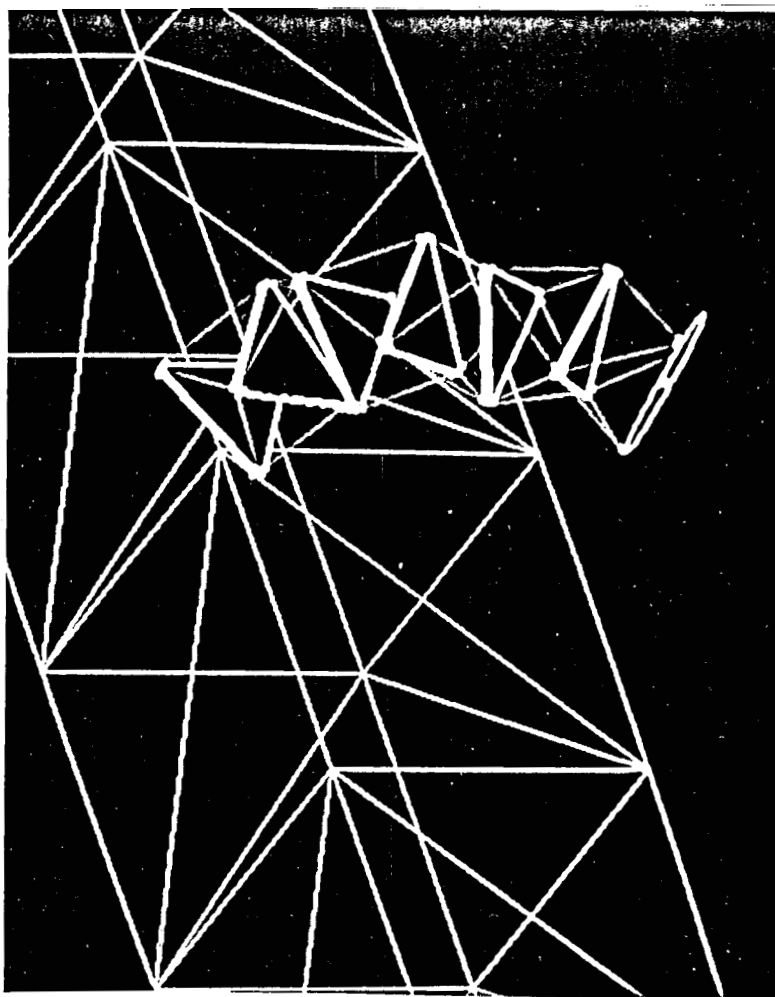
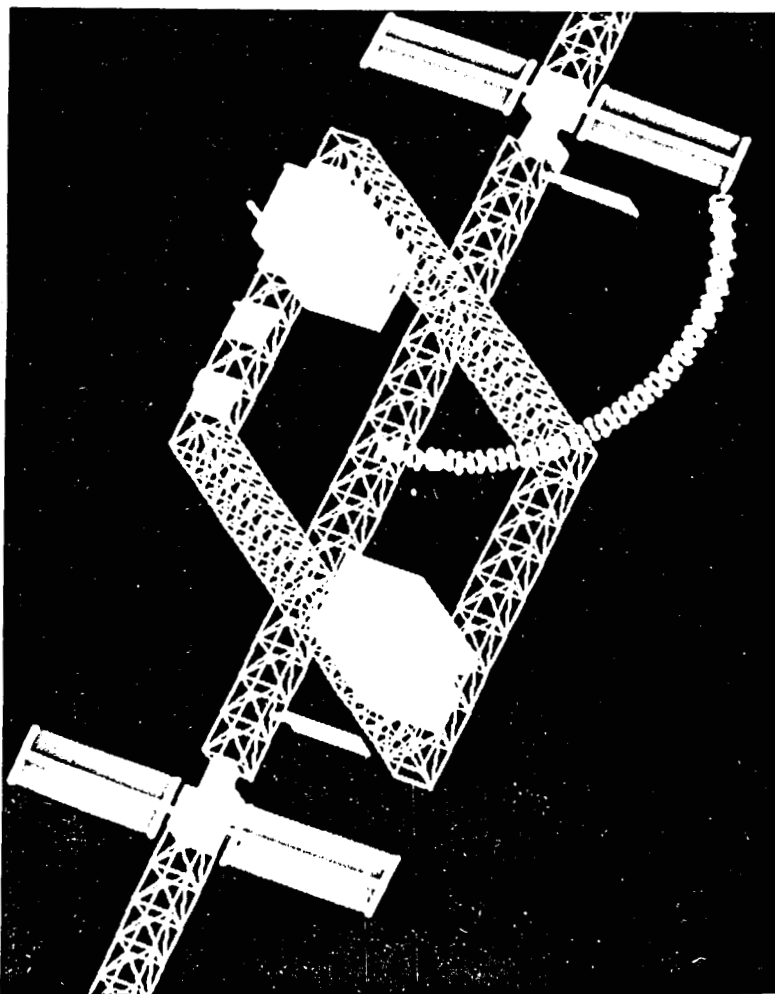
### **SYSTEM DESIGN EVOLUTION**

#### **POD MATES/DOCKS TO STATION RESOURCE NODE**

- No Tunnel or Expandable Tunnel Mechanism Required
- HOST Structure Attached to Station Structure
  - Single or Several Fixed Attach Points
  - Mounting to Moveable Base on Rail Structure Could Provide Increased Accessibility for POD Operations
- POD Geometry/Size Driven by Large Station Resource Node Docking Interface
- Stewart Tables (25) are Aluminum Triangular Structures with Double Clevis Connections to Enable Actuator Attach Points(6) to Elevate and Swivel but Avoid Torque Induced Rotation
- Study Concentrated on Acuator for 4 Table Ground Test
  - Flight Actuator Requires Longer Actuator with Increased Stroke Ratio Capability, Improved Motor Efficiency and Space Environment Adaption
  - Detailed Trade Studies Required Between Design Complexity of High Ratio (Stroke to Fixed Length) Actuator and System Weight Increases for More or Larger Tables to Meet Same 50 Meter Extension



CONCEPTUAL SYSTEM DESIGN



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Fig. 12 Host Rail Mounted at Space Station

## CONCEPTUAL SYSTEM DESIGN

### SYSTEM DESIGN EVOLUTION

#### POD MATES/DOCKS TO STATION RESOURCE NODE (cont.)

- Flight Design Actuator Characteristics
  - High Performance Permanent Magnet Motor (Samarium Based)
  - High Strength Aluminum Alloy Body
  - Actuator Rods of Stainless Steel
  - Ball Bearings Greased Like RMS (Braycote 3L-38RP Based on Perfluorinated Polyether)
  - Optimized Stroke to Length Ratio
  - Optimized Electrical Power Characteristics
    - Dependent on Shuttle and/or Station Interface and Other System Trades
- Actuator Size Selected For Power Determination -Fixed Length is 59 Inches with Stroke of 34.5 Inches ( Length Ratio is 1.58)
- **Conceptual Design Selection -POD Mates/Docks to Station Resource Node**
  - Substantially Less System Complexity
  - Lower Weight
  - Elimination of One Hatch
  - Direct POD Access by Crew

## **CONCEPTUAL SYSTEM DESIGN**

### **SYSTEM DESIGN EVOLUTION**

#### **USE OF TUNNEL AND STRUCTURE MECHANISM ONLY**

- Deploy Short Flexible Tunnel/Stewart Table Structure to Mate with Shuttle Docking Port and Provide Pressurized Crew Transfer Tunnel To/From Station
  - This Application Deletes POD and Uses Reduced Number of Stewart Tables
- Provides Several System Advantages
  - Lets Station Meet Orbiter via Extendable "Jet-Way" Docking Port
    - Increases Orbiter / Station Clearances During Docking Approach by Orbiter
  - May Enable Lower Impacts to Station Systems (Structure and Control) and Reduced Disturbances to Experiments (Especially Long Term Micro-gravity Experiments)
- Requires Expandable Tunnel Development

## **CONCEPTUAL SYSTEM DESIGN**

### **MANNED CONTROL STATION (POD) STRUCTURE AND MECHANICAL ELEMENTS**

- POD Structure Shape & Size Governed by:
  - Primarily the Large Station Docking Interface
  - Crew Room and Adequate Work Station Viewing
  - External Surface for HOST Attachment Structure/Radiators
  - Positioning of Manipulator Arms and TV Camera
  - Cargo Bay Envelope
  - Conceptual Structure Design Used for POD/Other Structure Weight Estimates
- POD to Truss Attachment Structure Supports Radiator Panels
  - Thermal Study Used Larger POD Volume-Radiator Area Can Be Reduced
- Additional Elements Supported by POD Structure
  - Manipulator Arms (2) - RMS Type End Effector for Non-Fixed Work Objects
  - RMS Standard Grapppler Fixture(POD Only Operation - Other RMS Systems)
- HOST POD Windows Based on Station Window Development(TBD Best Location)
- POD Thermal Study Used Space Station Micrometeoroid Protection Concept In Lieu of Goodyear Design of Non-Metallic Materials for Tunnel Protection
  - Thin Metallic Bumper and Anodized Surfaces Provide Longer Life
  - Reduces Effect of UV Rays & Atomic Oxygen on Protection Materials

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) STRUCTURES AND MECHANICAL ELEMENTS (cont.)

- Exterior Thermal
  - Combination of Micrometeoroid Bumper and Shield Material Selection
  - Active Thermal Control (Heat Rejection Biased) with Radiators on POD/Truss Structure
- Docking Port and Hatch
  - Standard Space Station Docking Structure
  - Smaller POD Hatch Selected to Minimize Internal Opening Clearance for POD
  - Interface Size and Location on POD of POD/Node Mating Substantially Affects POD Size / Geometry and Requires Detailed Study

## **CONCEPTUAL SYSTEM DESIGN**

### **MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS**

- Extension Structure Control Strategies and Implementation
- Dextrous Manipulators, RMS End Effector and Associated Controls
- Independent Environmental Control and Life Support
- Additional Subsystems
  - Communications /TV
  - Data
  - Electrical Power
  - Caution & Warning

The Additional Subsystems Will Use Standard Space Station Hardware & Interfaces

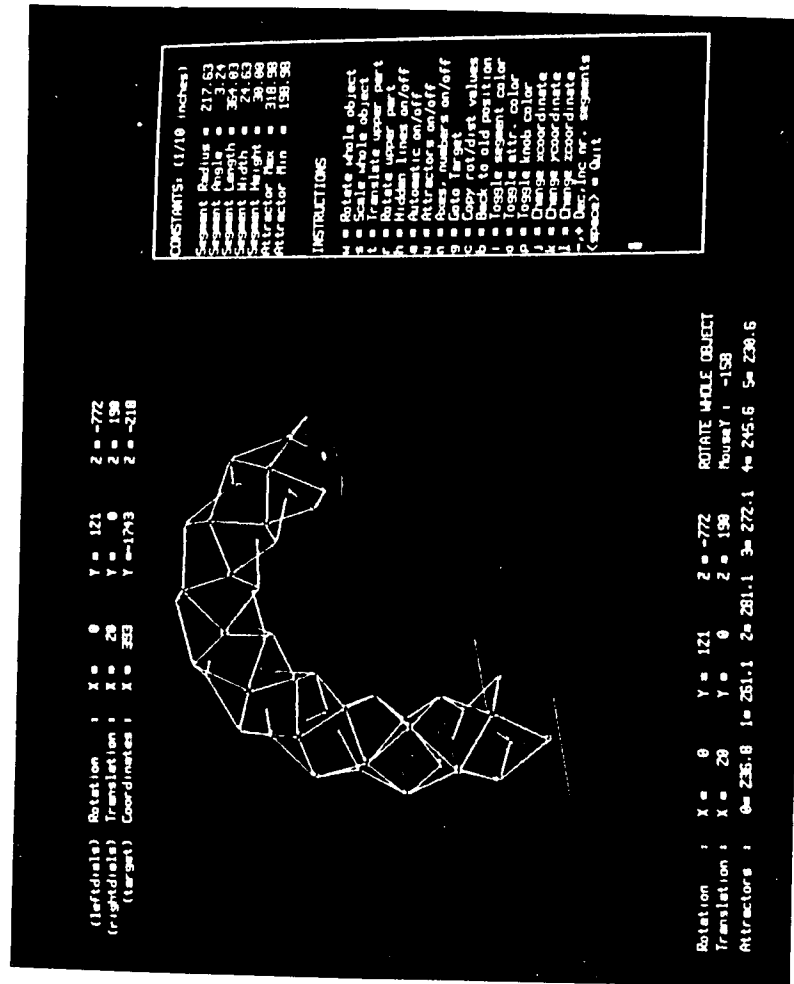
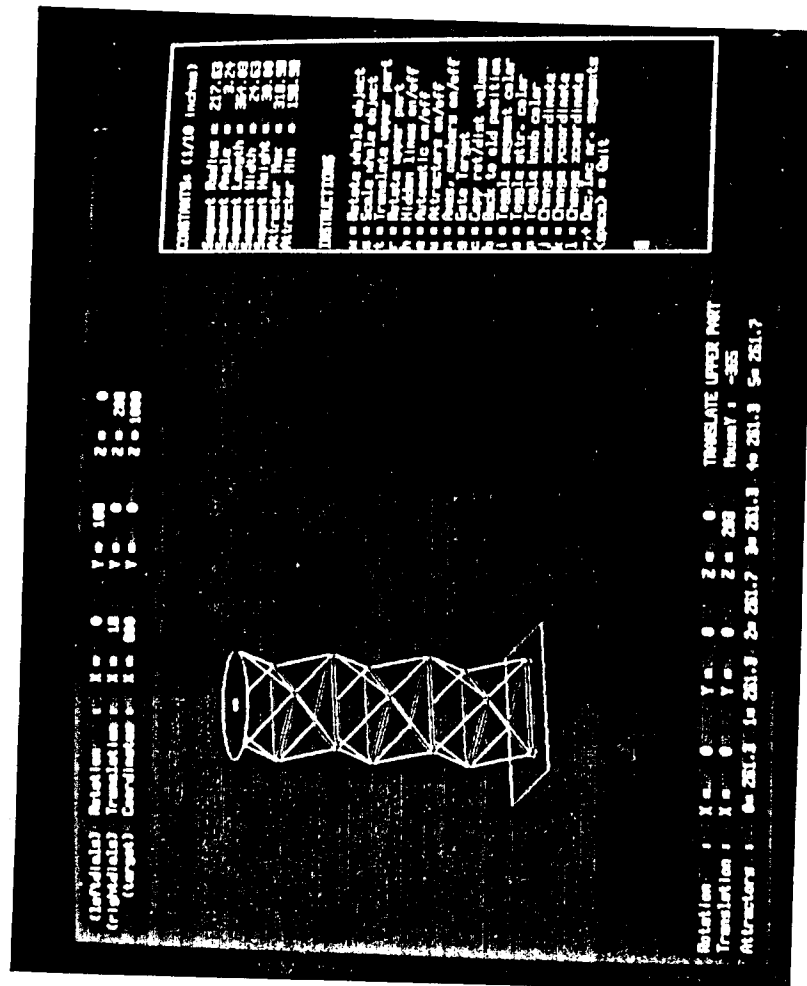
## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS

#### EXTENSION STRUCTURES CONTROL STRATEGIES AND IMPLEMENTATION

- Both Keyboard Input and Crew Control by Joystick Elected
  - Substantial Coarse Maneuvers by Keyboard to Reduce Crew Tasks
  - Fine Movements by Crew Joystick for Precision Positioning
- Several Control Strategies Investigated
  - Base-biased
  - Tip-biased
  - Equal-biased (Equal Emphasis to All Segments)
  - Form fit (Collision Avoidance)Using Two Methods of Control
  - Rate control
  - Position Control
- Equal-biased and Position Control Selected and Successfully Tested Using Computer Simulations
  - Exception May Be for Fine Movements at Workstation
  - Equal-biased Approach Compatible with Fixed Obstacle Avoidance Scheme (If Used In Sections of Tables)
- Video Showing HOST Maneuvers During Computer Simulations Is Available

# CONCEPTUAL SYSTEM DESIGN



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Fig. 13 Control Strategy Computer Simulations



## **CONCEPTUAL SYSTEM DESIGN**

### **MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS**

#### **EXTENSION STRUCTURES CONTROL STRATEGIES AND IMPLEMENTATION (CONT.)**

- Power Control of Actuators by Individual Power Controllers
  - Microprocessor Controlled Interface on Each Table
- POD Command Computer Controls Each Table's Controller via Data Buss
- Inputs to POD Command Computer by Joystick or Keyboard Representation of Location Coordinates

## **CONCEPTUAL SYSTEM DESIGN**

### **MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS**

#### **SHUTTLE RMS GRAPPLER, MANIPULATORS AND ASSOCIATED CONTROLS**

- A Standard RMS Grappler Fixture is Mounted on The POD to Provide for Grasping by Other RMS Devices (From Orbitor or Space Station)
  - For Standard Operations Without HOST Truss Structure
  - For Emergency Operations After POD Separation from the HOST Structure

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS

#### INDEPENDENT ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM

- POD ECLSS Selected to Operate at 14.7 psi
    - Saves Crew Time (Avoids Pre-breathing) and Pressure Differential Complexities
  - Design Based Primarily on Commonality with Station ECLSS and Use of Compatible EVA Life Support Systems
    - Substantially Higher Thermal Loads and Contingency Operation Duration Rule Out Most EVA Suit Components
  - Provides Independent Habitable Environment - One Person /8 Hrs
    - 16 Hrs Contingency Provided
  - Provides Air Cooling of POD Avionics
  - Derived Requirements for ECLSS
    - Avionics      700 Watts
    - ECLSS        240\* Watts
    - Environmental +100(-150) Watts
    - Metabolic    137 Watts
- \*Spacelab Performance Based. Also Power Requirement Input
- ECLS System Weight is ~306 lbs and Requires ~8 Cubic Feet of Internal POD Volume and 140 Sq. Ft. of Externally Mounted Radiators
    - Optimization of Avionics(Computer Power) Will Reduce Radiator Size/Weight

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS INDEPENDENT ECLSS (cont.)

- ECLS Subsystems Include:
  - Temperature and Humidity Control
  - Atmosphere Control and Supply
  - Atmosphere Revitalization
  - Fire Detection and Suppression
  - Water Recovery and Management
- ECLS System Includes Redundant Components
  - Cabin Air Fans
  - Coolant Loop Pumps
  - LiOH Canisters
- New Development Components Are Limited To
  - Cabin Air Fan
    - Resizing to Final POD Volume May Enable Use Of Existing Fan
  - Oxygen Bottle
  - Condensate Tank and Urine Collection Tank (Same Construction)
- Oxygen Sensor-Controller /Valve Assembly Adapted from EVA Suit to 14.7 Psi

# POD ECLSS BASELINE

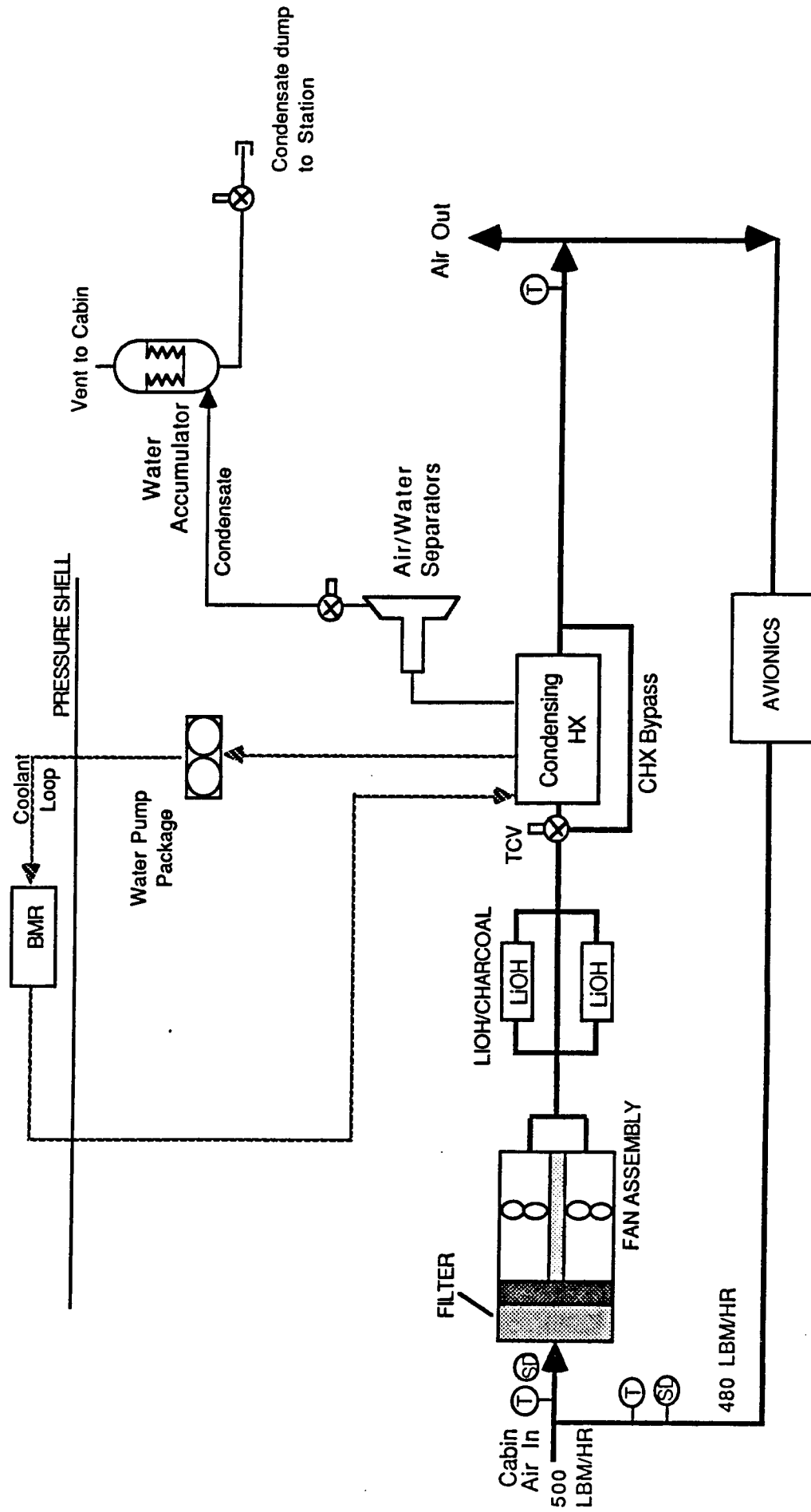


Fig. 14 POD ECLSS Baseline Schematic

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS INDEPENDENT ECLSS (cont.)

- Cabin Fan Carbon Dioxide Control Assemblies Scaled Down from Shuttle/Spacelab Hardware-Thermal Radiators Derived from Station Development
- Condensing Heat Exchanger & Water Pumps are Spacelab/Shuttle Derived
  - Water Separator Assembly is Spacelab Derived (Both ~50% Smaller)

#### Alternative Heat Rejection Subsystem

- Baseline Advantage is Use of Station Compatible Hardware and Low Power
  - Disadvantage is Large Radiator Area - 140 Sq. Ft.
  - Requires Additional Structure Between Truss and POD for Radiators
- Design Alternatives Could Reduce Radiator Area up to 70% (140 - 40 Sq. Ft.)
  - Probably Eliminates Need for Extra Radiator Structure
  - Provides More Flexible Design and Reduced System Weight
  - Requires New Component Development and Higher Power

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS INDEPENDENT ECLSS (cont.)

#### Advanced Systems

- Advanced ECLS Components Under Development by Space Station with Possible Application to POD ECLS
  - Regenerative Components for CO<sub>2</sub>/Moisture Removal
    - Solid Amine
    - Electrochemical
- Both Approaches Offer POD ECLS Simplification with Similar Crew Time
  - Removal for Regeneration
  - Changeout of LiOH Cartridges
- Overall Comparison Indicates a Weight Savings of ~ 20% for CO<sub>2</sub> Regeneration for Thirty 8-Hour POD Uses
  - Power Requirements Increase - 0 to 1200-1300 Watts for Regeneration of CO<sub>2</sub> Systems (Perform During Off-Peak Station Power Consumption)
- Selected ECLS System Will Meet Requirements and Is Based Primarily on Available or Derived Hardware
- Final Selection of a CO<sub>2</sub>/Water Removal System
  - Make After Further Advanced ECLS Development Work

# POD ECLSS SOLID AMINE

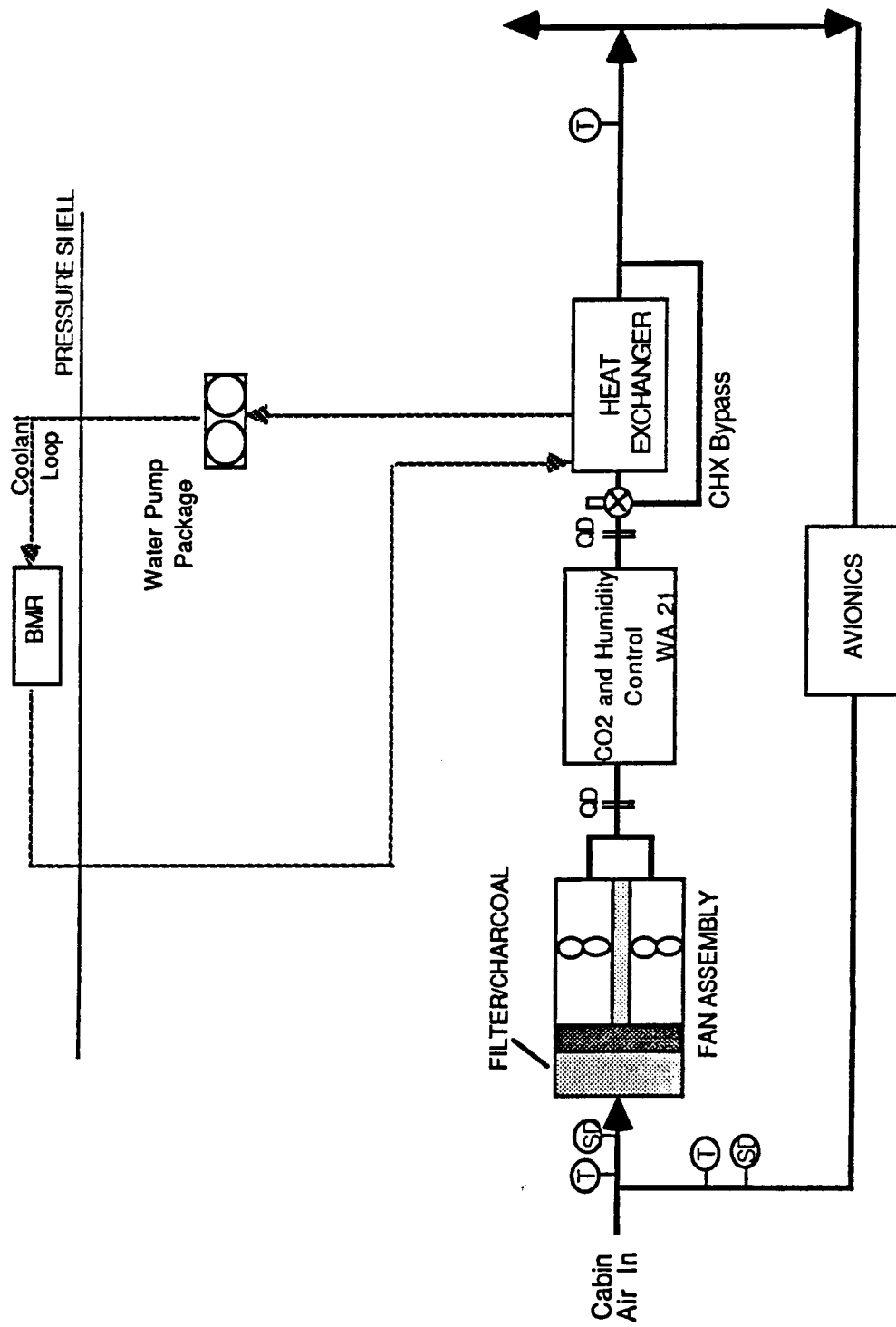


Fig. 15 POD Advanced ECLSS Schematic- Option 1



# POD ECLSS ELECTROCHEMICAL

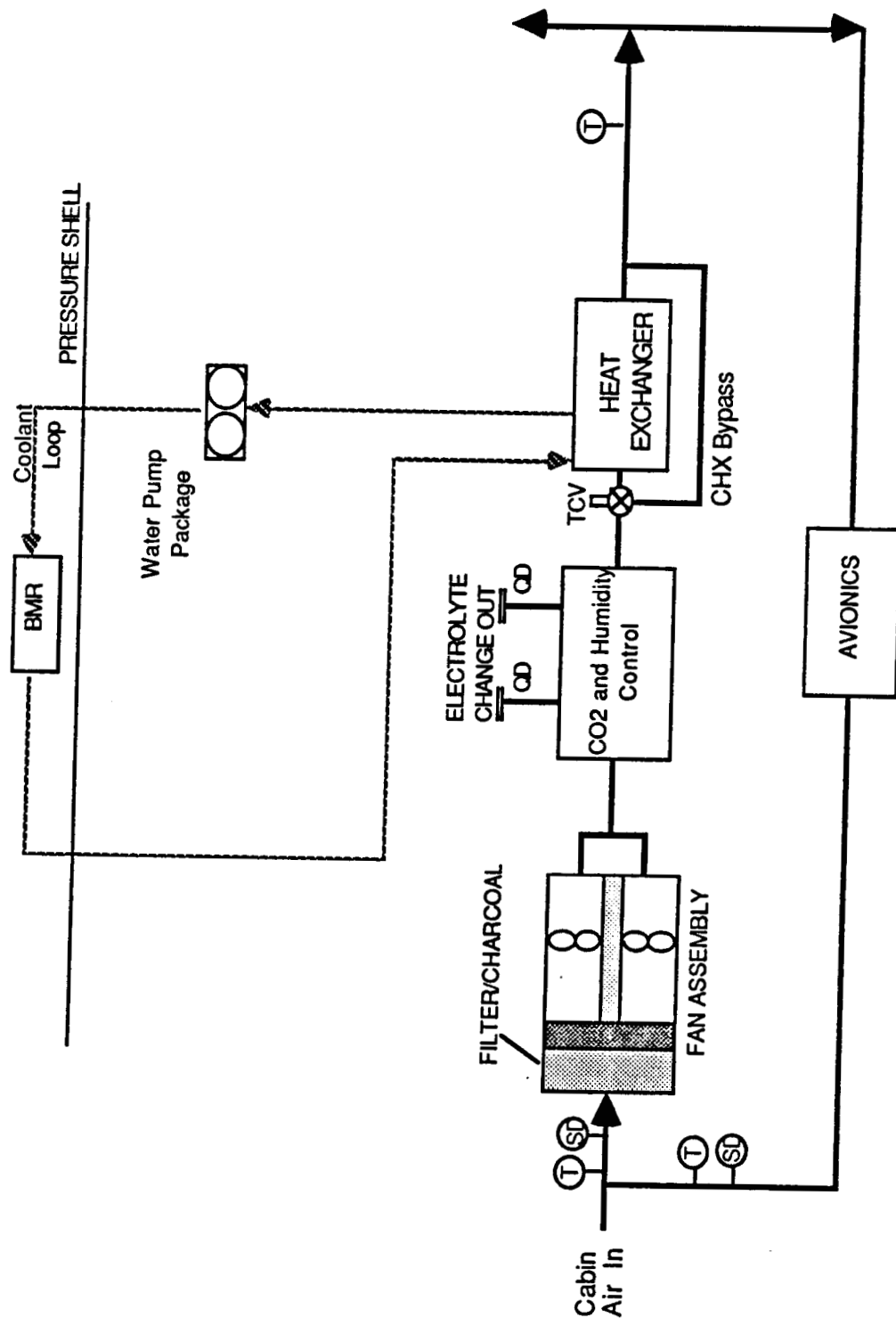


Fig. 16 POD Advanced ECLSS Schematic-Option 2

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS ELECTRICAL POWER

- Space Station Power is 208 volt, Single Phase, 20K Hz.
- HOST Study Assumed Station Conversion to Match Actuator & Other POD Requirements
- Ground Test Actuator Uses 24 volt dc (Shuttle Compatible)
- Power Requirements Analysis Based on Ground Test Actuator(Off-the -Shelf)
  - 1000\* Load Capability
  - 5.25 amps Current(@ 500\* Actuator Load)
  - Based on Conservative Manufacture's Rating
  - 0.5 inch/second Stroke Rate(@ 500\* Actuator Load)
  - Full Deployment-26.8 minutes(Table by Table Extension-Lowest Peak Power)
- Power Requirements per Actuator /Controller(Including Controller Inefficiency)
  - is 5.1 amps- 122.6 watts
  - Planned Flight Actuator Motor Enables at least a 20% Power Reduction

## CONCEPTUAL SYSTEM DESIGN

### MANNED CONTROL STATION (POD) POD OPERATING SYSTEMS ELECTRICAL POWER (cont.)

- Maximum Power Requirements per Table Extension/Retraction  
735.8 watts ( Plus 142.2 watts -Last Table Line Loss )  
Peak Power 877.9 watts - 36.6 amps
- POD Avionics and ECLSS Systems Requirement ~ 1010 watts(8HourDuration)
  - Use of Station ECLSS Assumed (Hatch Open) During Non-Use of POD
- Peak HOST Demand From Station is ~ 1900 watts ( Plus Station Conversion Losses )
  - Total Is Considered An Outside Requirement Before Actuator Motor Improvements and Avionics / ECLSS Optimizations
  - Further Study Using Higher Line Voltage(Reduce at Table ) versus Other Systems Impact Could Lower Peak Demand

## **CONCEPTUAL SYSTEM DESIGN**

### **CREW ACTIVITIES AND SYSTEM OPERATION**

- Manned Control Station ( POD ) Occupied by One Person and Contains All Controls for Operation of HOST System
  - Docking /Undocking POD
  - Directing POD to /from Work Area
  - Operating Manipulator Arms and POD End Effector
  - Managing ECLS System
  - Responding to Caution & Warning Displays
- Use of "Glovebox" Desirable - Depends on 14.7 psi Suit Development
- Crew Work Station Located Forward in POD for Maximum Operations Visibility
  - Foot Restraints Provided at Control Console
- Hand Controller Commonality with Station Preferable for Crew Efficiency
- Operator Uses Manual Controller (Joystick) and Computer Command for POD Positioning
  - Automatic Sequence Interruption by Operator is Mandatory
- Continued Study is Required During Design Evolution to Assure Two Failure Tolerance

## **CONCEPTUAL SYSTEM DESIGN**

### **CREW ACTIVITIES AND SYSTEM OPERATION (cont.)**

- Robot Arms Operated by Crew Member Through Manual Controllers (Joystick)
  - Secondary Method of Releasing Arm From Grasped Object or Jettison of Failed End Effector Required
- Planned Return to Docked Position by Computer Command
  - System Must Assure New Work Doesn't Add New Hazards in Return Route
- Manual Return Probably Requires Video Presentation
  - Command Inputs Coordinated with Visual Presentation to Assure No Confusion Exists Between Desired Directional Movement and Manual Controller Movement

## CONCEPTUAL SYSTEM DESIGN

WEIGHT ESTIMATE SUMMARY		LBS.
Exoskeleton Truss & Associated Hardware		<u>3800</u>
- Base, Tables, Actuators and Attachments Fittings		
POD/Radiator Attach Structures		<u>3550</u>
- Electrical Power, Control & Communication		
Lines Attachments and Table Electronics		<u>250</u>
POD		<u>1900</u>
- Pressure Shell (Incl. Windows, Hatch and Umbilicals)		
- External Structures/Mechanisms		<u>520</u>
- POD to Node Docking Structure (Unpressurized)		
- Radiators, Meteoroid Shield/Standoffs, Grapppler & Manipulators, End Effector, and Associated		
POD Hardpoints,		<u>560</u>
- Internal Hardware		
- Computer, Controllers, ECLSS,		
Communication/TV, Crew Aids		
Other Displays, Support Structures and Wiring		<u>820</u>
Subtotal		5700
Contingency (25%)		<u>1425</u>
Total		7125

Fig. 17 Conceptual Design Weight Estimate

## **FAILURE MODE & EFFECTS ANALYSIS**

- Initial Analysis Concentrated on Crew Safety
  - Performed for Tunnel Version - Conceptual Design Eliminates Tunnel/Tunnel Systems
- Specific Failure Mode Probability or Risk Would Be Performed During Hardware Design Evolution
- Five Major Systems or Elements Examined
  - Conceptual Alternate Operation or Crew Transfer Modes to Assure Crew Safety Were Determined
    - Base Airlock Hatch
    - Personnel Access Tunnel
      - Fabric - Outer Latch - Actuators
    - Segment Base Truss Structures
    - Segment Actuator
      - Motor - Pivots - Rods - Potentiometers - Control Wiring
    - Main Control Wiring - Power Lines - Trunk Power Lines
  - Control Pod
    - Life Support System - Leakage - Communications - Operator
    - Control System - Power System - Manipulator Arms - Access Hatch - POD/Truss Release Mechanisms

## **FAILURE MODE & EFFECTS ANALYSIS (cont.)**

- Potential Failure of Hardware Leading to Inability of POD to Remate with Flexible Tunnel Drives Substantial Design Requirements
  - POD Separation Mechanism
  - Backup Power Battery
  - Additional Hardpoints for Grappling By Station Devices
  - Alternate Node for POD Mating
  - Amount of LiOH Cartridges and Fluid Accumulation Capacities
- Possible Methods for Returning POD to Node
  - Self Help with Manipulator Arms Along Available Structure (Use Backup Battery Power)
  - Use of Other Station Service Devices Attached to a POD Grapple Point
  - Use of EMU (or Potentially OMV) to Return POD to Node Proximity and Complete Maneuver with Manipulators
- Specific Disconnect Approach Is TBD
  - Desire Slow Reversible Mechanical Separation e.g. Apollo-Soyuz Docking Mechanism and Electrical Connection
- Conceptual Design Reduces Failure Modes by Hardware Elimination
  - Deletes Personnel Access Tunnel, Associated Mechanisms and Extra Crew Hatch



## **FAILURE MODE & EFFECTS ANALYSIS (cont.)**

- Adequate Countermeasures Appear Feasible to Provide Crew Safety
  - Final Methods to Assure Two Failure Tolerance Require Further Study
  - HOST Requirements and Hazard Analysis Need to Proceed in Parallel with Station Design

## **ACCOMMODATIONS ASSESSMENT**

### **SPACE SHUTTLE**

- Hardware Accommodations and Interfaces
  - HOST System Fits Within Cargo Bay Envelope
    - Maximum Diameter - 7 Feet 9 Inches (10 Feet 6 Inches with Tunnel)
    - Length - 49 Feet - 5 Inches (Plus Attachment Structure)
  - System Requires Structural Attachment at Both Ends to Orbiter Hardpoints
    - Potential Use of Existing Hardware Requires Examination
  - POD Hardpoints Can Be Compatible w /RMS and/or Station Maneuvering Arms
  - Potential Accommodation of HOST POD Interface with In - Bay Orbiter EVA Tunnel Element
  - No Unusual Orbiter Services or Accommodations Determined
- Operations
  - Potential HOST System or RMS/POD Only Operations from Shuttle Like Other RMS/Cargo Operations
  - Transfer /Attachment of HOST System to Station Like Other Station Assembly Tasks

## **ACCOMMODATIONS ASSESSMENT (cont.)**

### **SPACE STATION**

- **Hardware Accommodations and Interfaces**
  - Conceptual Design Primary Interface Is POD to Station Resource Node and Extension Truss to Station Structure (Potential for Rail Mounting on Station)
  - HOST System Conceptual Design Uses Standard Station Services
    - Assumption of Station Power Conversion Is Exception
  - Effective and Efficient Power Usage for HOST Station Assembly Tasks Suggests Further Electrical Interface Tradeoff Studies
- **Operations**
  - Conceptual HOST Installed Configuration (POD to Station Resource Node)
    - Offers Direct Crew Access for Simplified Station Operations and Lower Risks with up to 50 Meters Accessibility to Station Work Locations
  - Attachment of HOST Base to Moveable Station Attach Point Offers Greatest Station Accessibility and Operations Flexibility
  - Power Usage Remains to be Confirmed as Compatible with Station Power Timeline
  - HOST Operation's Disturbances to Station Control and Microgravity Experiments Remain to be Confirmed as Within Acceptable Limits

## **PRINCIPAL AREAS REQUIRING FURTHER DEFINITION**

- Determination of Initial Mode(s) of Operation
  - Truss and Actuator Design Tie Directly to Mode Selection
  - Initial Design Driver Decision Is Requirement for Tunnel
- Initial HOST Installation at Station
  - Determination of Installation or Operation Requirements for Remote Control Operation of HOST
- POD Design Incorporating All Requirements and Constraints (Station Updates)
- Loads and Dynamic Disturbances, Control Methods (Including System Dynamics) and Power Usage Interaction
- Orbiter Interfaces and Initial Operations from Orbiter
- Space Station Based Storage During Early Assembly
- Additional Computer Simulations with Flight System Design Parameters

## **PRINCIPAL AREAS REQUIRING FURTHER DEFINITION(cont.)**

- Actuator Design
  - With High Extension Ratio and High Efficiency Motor
- Manipulator Design - Primarily Space Adaption
- Partial System Demonstration -Prototype 4 Tables (Truss/Actuators)
- Emergency Recovery of POD / Crewman and Other Hazard Analysis/FMEA's
- HOST Operation Dynamics' Influence on Space Station
  - Determine Acceptable HOST Operational Modes and Rate of Movement Limits

## **SUMMARY**

- HOST System Provides Accessibility for Multiple Space Station Tasks without EVA
- HOST Uses Low Risk Technology
- Actuator Is Primary Unique Hardware Development Component
- Control Methodology and Logic Demonstrated Through Computer Simulations
- HOST System Saves Crew Time and Reduces Fatigue
- POD to Node Attachment Offers Lower Complexity and Direct POD Access
- Tunnel/Table Structure Alone Offers Attractive Concept for Orbiter Mating With Station by means of Extendable "Jet-Way" from Station to Orbiter
- HOST System Offers Flexibility and Growth
  - Potential Use from Orbiter - Two Modes (POD / HOST or POD only w / RMS)
  - Use As Station Docking Port Extension for Orbiter
  - Fixed Attachment of HOST at Space Station
  - Moveable Attachment Location on Space Station (Rail Mount)
  - Evolution to Space Station Proximity Free Flyer
- System Complements or Substitutes for other EVA /Maneuverable Systems

## **RECOMMENDATIONS**

- Assess Concept's Potential For Early and Follow-on Programmatic Benefits  
In Context of Total Space Station Requirements and Evolution
- Perform a Phase A Definition Under Direction of a NASA Field Center

## Appendices



## **Appendix #1**

### **Flexible Tunnel Material Selection**

## Flexible Tunnel Material Selection

### 1. Introduction

If a HOST application is chosen that requires a tunnel it would be an inflatable structure. The candidate material or materials for the construction of the tunnel will not only have to meet the strength requirements but also the requirements associated with crew safety and ground and space environment effects.

Two applications of flexible materials in orbiter applications are the astronaut's space suit and the Spacelab transfer tunnel flexible sections. The flexible sections of the tunnel consisted of two plies of fabric, steel beads and fillet. The fabric consists of Nomex unidirectional cloth coated with Viton B-50 elastomer with each ply biased at  $\pm 15$  degrees to the flex element centerline. Overall thickness of the composite is approximately 0.11 inches with the individual thickness of the Nomex being approximately 0.025 inches. Each ply of Nomex is coated on each side with approximately 10 mils of Viton. A ten mil thickness of Viton is added to the inner and outer surfaces during the layup. The bead itself was made from 51 continuous wraps of 0.037 diameter steel wire which tested to an ultimate strength of over 15,000 pounds. The debris shield used to protect the flexible element from falling debris is constructed of a stretch-type cloth of Kevlar 29 sewn at each side to preformed and precoated Nomex tapes which are fastened to the inner rings by clamp bars. Viton B-50 elastomer and Nomex cloth were chosen because of the long life and off-gassing, flammability requirements.

Goodyear Aerospace Company (GAC) conducted a search for existing materials for space applications through an industry survey and literature review. A material selection criteria, consisting of the following, was applied to the candidate materials.

- a. Crew safety associated with avoidance of flammability and toxic hazards.
- b. Ability to withstand ground environment effects, including humidity, temperature extremes and fungus.
- c. Compatibility with the space environment, considering mechanical properties, thermal conductivity, gas tightness, micrometeoroid production, and packageability.
- d.. Mass properties efficiency.

## 2. GAC Material Selection Conclusions

The GAC study regarding nonflammability outgassing, oxygen permeability and temperature effects yielded the following conclusions:

- a. No available plastic films, flexible adhesives or thin gage elastomers were found that could meet Category A upward flame propagation rate test requirements in a pure oxygen environment. However the shirt sleeve environment of the POWER tunnel may considerably reduce this rate especially for the slow burn materials. (Table 1)
- b. It is feasible to construct a satisfactory flame/gas barrier from a combination of nonflammable materials in a manner to enable a composite wall system to pass an upward flame propagation test.
- c. A 3-layer "flame barrier" element consisting of aluminum foil/Refrasil cloth/aluminum foil proved to be the best of several investigated. (Because of the high melting point of the Refrasil cloth and the heat sink characteristics of the aluminum foil, the system affords excellent shielding for only a small additional weight.)
- d. GAC recommended that NASA adopt a pressurized diaphragm flammability test (or one similar) to determine the effects of a sizable fire on the surface of an inflatable structure wall. (This test was important in the selection of the XPB-14A flame/gas barrier design by GAC.)
- e. Low temperature deployment was considered to be the most critical requirement for any expandable space structure. Cold temperature behavior of the XTC-4 and XTC-6 wall systems were investigated during the qualification test phase of the GAC program. Fold tests demonstrated satisfactory deployment capabilities for both systems at -5 degrees F with possible deployment capabilities extending to a maximum of -43 degrees F.
- f. Maximum and minimum limits of heat transfer attainable with XTC-4 and XTC-6 wall systems are expected to provide most ranges anticipated for future space mission structural design requirements.

TABLE 1 SUMMARY OF QUALIFICATION TESTS PERFORMED ON SUBCOMPOSITE  
AND TOTAL COMPOSITE FINAL CANDIDATES

Component Test	Flame/Gas Barrier, XPB-14A	Structural Layer, XSL-3	Micromet- eoroid Barrier XMB-4	Outer Cover, XOC-2	Total Wall Composite		Super-Insu- lation Blanket
					XTC-4	XTC-6	
1. Flammability 100% Oxygen at 6.2 psia a. Upward flame Propagation Test b. GAC Diaphragm Flammability Test	X X					X	(1)
2. Packageability a. Elastic Recovery; 75% compression for 30 days at 180 deg. F b. Effect of Temperature on deployment force; -100 to 75 deg. F c. Single fold test; ability to unfold after 7 days at 180 deg. F d. Effect of repeated creasing on gas impermeability			X		X  X	X  X	(2)
3. Micrometeoroid Impact NASA-MSC-LRC Test					X (20 6"x6" specimens supplied to NASA)	X (20 6"x6" specimens supplied to NASA)	X (20 6"x6" specimens supplied to NASA)
4. Thermal/Vacuum Exposure; 6x10 <sup>-4</sup> mm Hg. 48 hours at 180 deg. F	X						
5. Effluent Gas Analysis a. Odor b. CO c. Total Organics	X X X						
6. Ply Adhesion	X					X	
7. Effect of Thermal Shock; -320 deg. F to 250 deg. F					X	X	
8. Stress-Strain Properties -100 deg. F to 250 deg. F	X	X Single strand @ 75 deg. F	X				X
9. Taber Abrasion	X			X			
10. Tear Resistance	X						X
11. Puncture Resistance	X	X combined with flame gas/barrier				X	
12. Humidity Resistance					X	X	
13. Fungus Resistance					X	X(3)	
14. Bleeding Resistance				X			
15. Solar Absorptance and Infrared Properties				X			
16. Thermal Conductivity					X	X	X
(1) Super-insulation blanket burns in 100% Oxygen at 6.2 psia - not required to pass Category A Test (2) Super-insulation considered very packageable - no problems anticipated in this area (3) Same material as used in XTC-6 evaluated							

- g. A step-by-step fabrication process of XTC-4 and XTC-6 wall systems was defined in sufficient detail to produce space structures of "flight hardware" quality.
- h. Inflatable/expandable structure technology is now available for manned space mission applications such as space station structures, airlocks, lunar shelters, and other applications.
- i. Strength-to-weight ratio comparisons of expandable versus-conventional hard structures were determined to be nearly equal at the time of the 1970 study program.
- j. Comprehensive NASA-WSTF laboratory tests of single layer materials and flame/gas barrier composites substantiated material selections and evaluations by GAC. Table 2 presents the summary of test results obtained on these materials.

### 3. GAC Test Module Evaluation

The results of GAC's qualification test program were not totally conclusive regarding potential effects of temperature upon packageability and deployment capabilities due to limitations inherent in testing small two-dimensional samples. Therefore, a cylindrically configured 3-foot-diameter, 5-foot-long structural test module was fabricated:

- a. The design operating pressure was 14.7 psi with a safety factor of 3 (successfully demonstrated).
- b. Packaging attained an inflated ratio of 4:1.
- c. The module demonstrated satisfactory deployment characteristics in a vacuum environment at temperatures as low as -30 degrees F. No structural degradation was demonstrated during a 14.7 psi proof pressure test following low-temperature deployment.

TABLE 2 SUMMARY OF TEST RESULTS OBTAINED ON MATERIALS SUPPLIED TO NASA-WSTF FOR EVALUATION

MATERIAL	THICKNESS IN.	MANUFACTURER OR SOURCE	UPWARD FLAME PROPAGATION RATE IN (a) 100% OXYGEN AT 6.2 PSIA		ODOR TEST (a)		
			PROPAGATION RATE IN/SEC	OBSERVATION	MAX. ALLOW. SCORE = 2.5		
					(A)	(B)	(C)
Mosites 1066 Fluorel Adhesive	(b) 0.002	Mosites Rubber Company, Inc.	3.68	Burned with orange flame	0.2	0.1	0.9
RL-3788 Fluorel Adhesive	(b) 0.002	Raybestos Manhattan Inc.	0.88	Burned with orange flame	0.2	0.3	1.3
B1677 Beta Fabric	0.007	J. P. Stevens & Co., Inc.	0.00	Melting in immediate area of igniter	0.2	0.4	1.0
Aclar 33c Film	0.001	Allied Chemical Co.	3.32	Burned with orange flame	0.3	0.4	0.8
Mosites 1062-C Fluorel Sponge	0.050	Mosites Rubber Company, Inc.	0.390	Burned with orange flame	0.0	0.4	1.6
XPB-10 Composite	0.065	Goodyear Aerospace Corp.	0.00	Failed to support combustion	0.1	0.5	1.6
Kapton Film	0.0005	E. I. duPont de Nemours & Co., Inc.	3.59	Burned with orange flame	0.1	0.0	0.4
Lite Flex K20 Asbestos Foam	0.75	Rex Asbestoswerke Schabisch Mail, West Germany	0.00	Failed to support combustion	0.2	0.3	1.2
C-100-28 Refrasil	0.014	Hitec	0.00	Failed to support combustion	0.1	0.0	0.4
XPB-14A Composite	0.070	Goodyear Aerospace Corp.	0.00	Failed to sustain combustion	0.2	0.4	1.3
Al-4 White Se Polyester Foam	1.00	Merryweather Foam Latex Co.	50.00	Burned with orange flame	0.2	0.4	1.4
AD 917 Vitel Adhesive	(c) 0.002	Goodyear Tire & Rubber Co.	2.73	Burned with orange flame	0.2	0.1	0.6
XPB-14A-1(d) Composite	0.070	Goodyear Aerospace Corp.					

MATERIAL	CARBON (a) MONOXIDE, gm/gm MAX. ALLOW. 25.0	TOTAL (a) ORGANICS, gm/gm MAX. ALLOW. 100.0	FLASH AND (a) FIRE POINT TEMPERATURE MIN. ALLOW. 450 DEG. F	DTA TEMP. OF MAX. EXOTHERM, DEG. C	TGA			MSC TEST REPORT NUMBER
					TEMP. OF MAX. ENDOTHERM, DEG. C	TEMP. OF INITIAL WT. LOSS, DEG. C	WT. CHANGE %	
Mosites 1066 Fluorel Adhesive	2.5	1.6	None to 315 deg. C. No visible change	280	None	255	0.6	2300
RL-3788 Fluorel Adhesive	0.9	1.7			None			2301
B1677 Beta Fabric	1.3	0.4	None to 315 deg. C	>315	None	280	0.7	2302
Aclar 33c Film	1.3	13.0	None to 315 deg. C	>315	210	>315	0.1	2303
Mosites 1062-C Fluorel Sponge	0.9	13.0	None to 315 deg. C. No visible change	>315	None	300	1.1	2304
XPB-10 Composite	4.6	571.0	None to 315 deg. C. No visible change	>315	None	245	1.2	2305
Kapton Film	2.5	5.9	None to 315 deg. C. No visible change	>315	None	80	0.6	2349
Lite Flex K20 Asbestos Foam	4.5	15.0	None to 315 deg. C. No visible change	>315	None	75	3.8	2350
C-100-28 Refrasil	0.8	0.5	None to 315 deg. C. No visible change	>315	90	<25	4.6	2351
XPB-14A Composite	0.9	102.0	None to 315 deg. C. No visible change	>315	None	160	1.1	2352
Al-4 White Se Polyester Foam	0.8	1.5	Flash Point, 271 C No fire point to 315 C	280	80	90	15.4	2353
AD 917 Vitel Adhesive	1.4	1867.0	Flash Point, 271 C No fire point to 315 C	>315	None	90	5.8	2354
XPB-14A-1(d) Composite	1.3	15.0						2352

- (a) Tested in accordance with MSC-D-NA-0002  
(b) Applied to one side of 0.001" thick aluminum foil  
(c) Applied to two sides of 0.001" thick aluminum foil  
(d) XPB-14A-1 Same as XPB-14A except processed for minimum adhesive solvent entrapment

- (A) 1-part sample times, to 25-parts O  
(B) 1-part sample times, to 8-parts O  
(C) No reaction

#### 4. Micrometeoroid Protection

Micrometeoroid countermeasures rank with previously discussed flammability safeguards as major crew safety concerns for space structures. GAC selected flexible polyurethane foam as a micrometeoroid barrier of preference for inflatable/deployable structures based upon company-sponsored hypervelocity particle impact tests conducted at Illinois Institute of Technology and tests conducted at GAC's RTD Dayton facility in the early 1960's.

##### a. Micrometeoroid Protection Material Candidates:

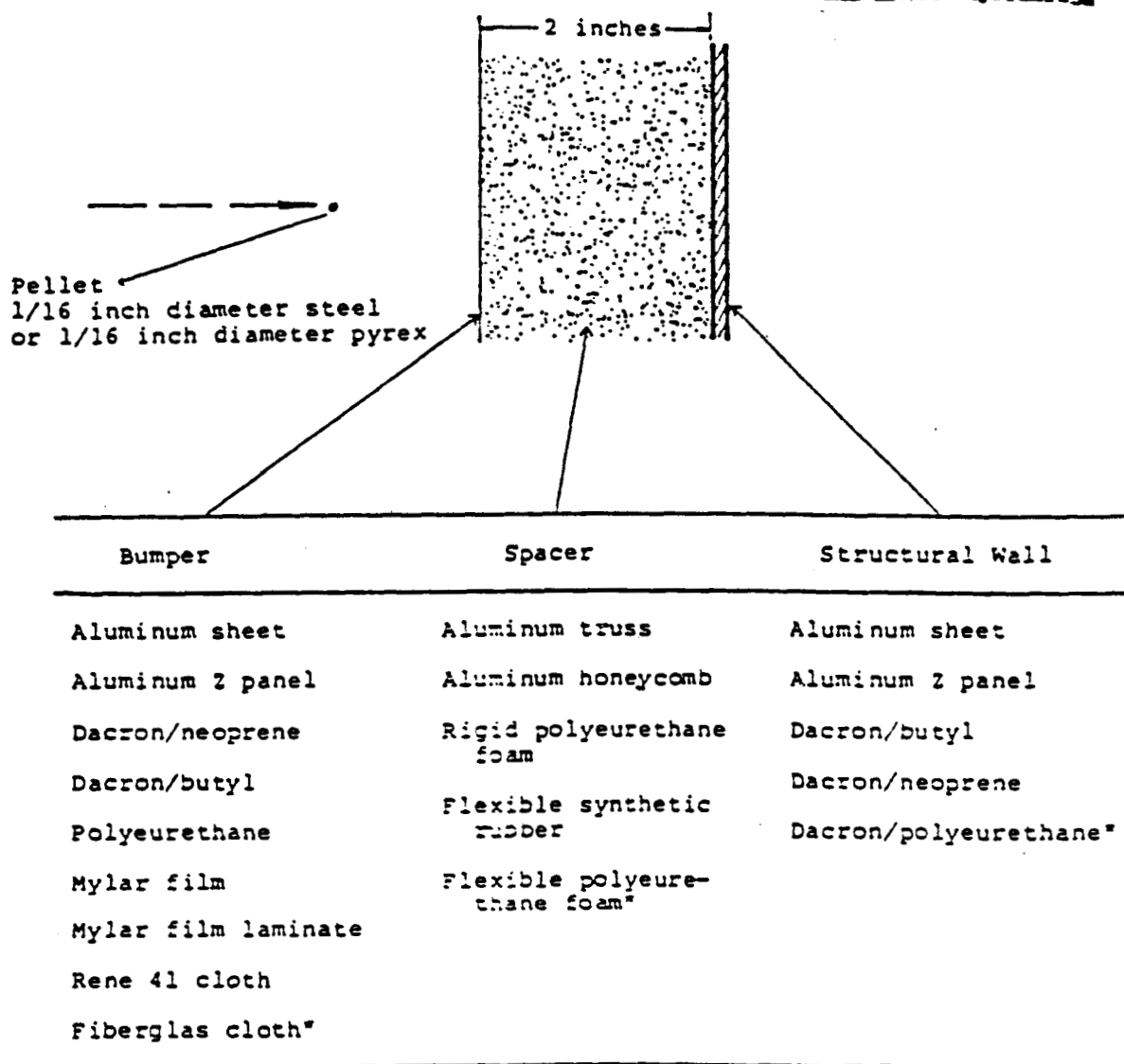
GAC-sponsored research analyzed different material characteristics applied to three-part micrometeoroid protection systems consisting of a bumper, a 2-inch thick spacer, and a structural wall.

- o Of nine candidates tested, Fiberglas cloth was selected as the material of choice for a bumper.
- o Of candidates tested, flexible polyurethane foam was selected as the material of choice for a spacer.
- o Of five candidates tested, Dacron/polyurethane foam was selected as the material of choice for a structural wall.
- o Figure 1 presents types of materials tested for micrometeoroid protection systems to be used with inflatable or flexible structures in space. These data can be used as a starting point for additional tests of materials alternatives for manned habitats, hangars, and other applications.

##### b. Micrometeoroid Protection Test Conclusions:

As a result of hypervelocity tests (0.0045-gram particles at 22,000 ft/sec and 0.005-gram particles at 30,00 ft/sec), it was concluded that flexible polyurethane foam of 1.2 pcf density was equivalent to a single sheet of aluminum of 15 times the mass per unit area. (Thus, a 2-inch thickness of 1.2 pcf foam was considered to be equivalent to an aluminum sheet 0.53 cm thick [ $1.44 \text{ gm/cm}^2$ ] with respect to penetration resistance.)

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\* Recommended materials

Reference: "Effects of Hypervelocity Particle Impacts on Composite Materials for Expandable Structures Applications," B.W. Reynolds, Goodyear Aircraft Corporation, Dayton, Ohio, 1962.

FIGURE 1 MATERIALS FOR MICROMETEORIDE PROTECTION



- o The density of the foam barrier was increased in development studies from 1 to 2 lb/ft<sup>3</sup> to provide nonflammable material. Increasing density did not increase particle penetration barrier characteristics.
- o A different type of barrier material was recommended for the expandable rigidized material concept. This applies a flexible urethane mesh (Scott Foam 10 PP1) of 1.8 lb/ft<sup>3</sup> density. The material can serve as a basic mechanism for rigidizing structures as well as a micrometeoroid barrier since the mesh is an ideal substrate for impregnation with gelatin resin. (The normally flexible mesh material when impregnated, may be rigidized by vacuum curing of the resin.)
- o Additional tests will need to be made on representative materials with and without rigidization to determine resistance to penetration by micrometeoroids and space debris.

#### 5. Spacelab Transfer Tunnel Tests

GAC conducted leak tests on the Spacelab-Shuttle transfer tunnel:

- a. The flex element material (XA30A553) was examined to ensure that the two plies of each material were completely bonded together and that no residual MEK was trapped in the elastomer. (No irregularities, no debonds, no blisters were noted before, or after the specimen tests.)
- b. Zero permeability was measured for the materials over an extended period with helium gas, indicating that the material leak rate was less than 30 sccm for differential pressures of 14.9 psi.

- c. GAC had to determine whether the Shuttle flex section leak test data met the specification requirement that a 14.9 psi constant internal pressure would not produce leakage exceeding 0.116 lb/day. The test was conducted allowing the internal pressure to decrease with pressure as a consequence of leakage while the specification was for a leak rate at a constant internal pressure of 14.9 psi. GAC developed a mathematical model of the system as tested with emphasis of the leakage process which permits the pressure to decrease with time. GAC then validated the model by comparing with the measured test data.

## 6. Penetration Leakage Estimates

Analyses have been performed by GAC to determine how much time an astronaut would have to find a puncture leak and repair it.

- a. An extremely small hole of 0.003 inch diameter would be very difficult to find, requiring 90 days for a 510-ft vehicle volume to leak down from 11 psi to 8 psi. A considerably larger hole of 0.10 inch diameter could probably be found by sound, requiring approximately two hours for the same pressure decay. (An astronaut should still have adequate time to find and plug such a leak before cabin pressure drops to a dangerous level.)

## 7. Crack Propagation Prevention

GAC conducted a leak-before-burst test of the flex section of the Spacelab Transfer Tunnel to determine whether it was stable under limit conditions with readily detectable damage. Similar tests must be conducted to verify crack propagation containment in other safety-critical inflatable/flexible space structure applications. The intentionally induced parallel and perpendicular yarn cuts did not grow or leak significantly when raised to 15.9 psi.

8. The following components and materials were tested by GAC for space applications:

A. 1-Person Expandable Airlock (Figure 2)

Project	Design, fabrication, and evaluation of a 1-person expandable airlock 4 feet in diameter, 7 feet long that could be stored in a minimum volume condition when not in use.
Sponsor/ Contractor	NASA-LRC; Prototype constructed by Whittaker
Construction	The airlock structure consisted of polyester cords and fiber glass rings to carry the longitudinal and circumferential loads, respectively. A fiber glass dome containing valves for pressure equalization formed the hatch cover. A motor-driven mechanism was used to retract the airlock into the packaged configuration.
Package Size	A deployed-to-retracted packaging ratio of 4:1 was achieved. This might have been improved by reducing the stiffness of the wall cross section and by applying translation plus rotation packaging used for Moby Dick.
Weight	213 pounds total, including 61 pounds for the retraction mechanism.
Pressurization	10 psi design pressure with a safety factor of 5; tested at 29.4 psi.
Conclusions	1-Person Expandable Airlock material is a good candidate for POWER tunnel material. However, requirements for extended use of such materials in space will involve additional factors such as fatigue and hot/cold temperature extremes which will greatly change the final design of tunnel material.

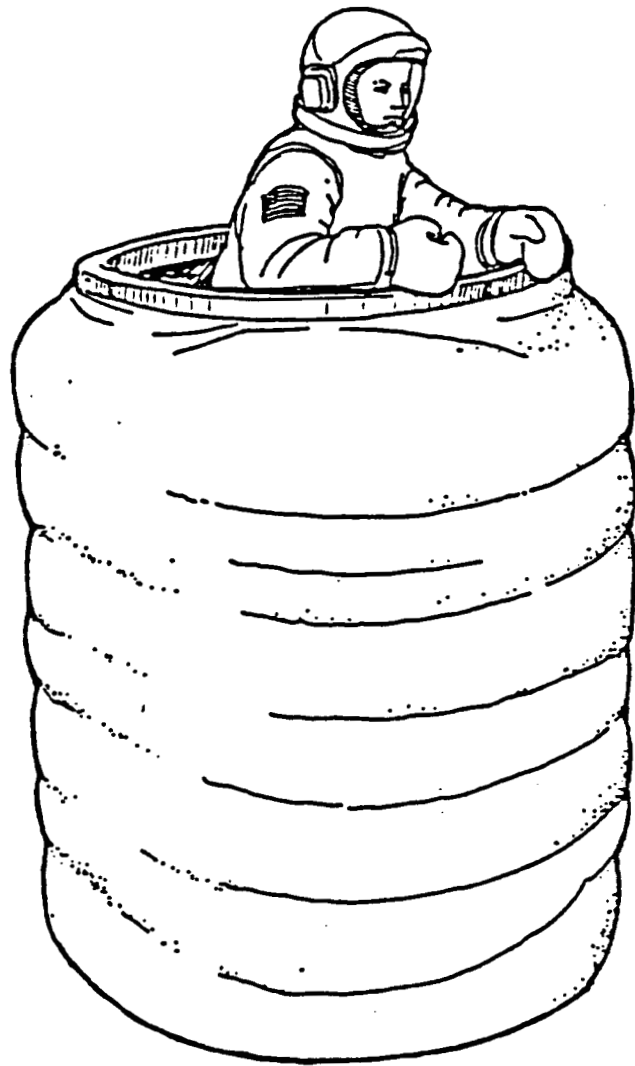


FIGURE 2 1-PERSON EXPANDABLE AIRLOCK

## B. Spacelab Transfer Tunnel (Figure 3)

Project	Design, fabrication, and evaluation of a 4 foot diameter flex section for the transfer tunnel between the Shuttle crew cabin and Spacelab module to minimize interface section loads resulting from axial, lateral, torsional, and rotational displacements caused by installation, thermal gradients and maneuvering.
Sponsor/ Contractor	NASA-MSFC; prototype constructed by GAC under a subcontract with McDonnell Douglas Technical Services Company (MDTSCO)
Construction	Flexible elements consist of 2 plies of Nomex unidirectional cloth fabric coated with Viton B-50 elastomer. The fabric plies were wrapped around steel beads made from 51 continuous wraps of 0.037 inch diameter wire with fillets added to the outer diameters to ensure a smooth transition. Debris shields constructed of Kevlar 29 protected the flexible elements from falling debris.
Package Size	The 170.5 inch length compressed to 20.5 inches.
Weight	Total 756 pounds included the flexible structure, bladder, micrometeoroid blanket, rings, pulley and cables.
Conclusions	Spacelab Transfer Tunnel material is a very good candidate for POWER tunnel material. Reliability of this material can be further increased by the use of higher order Kevlar presently available. (Kevlar 49)

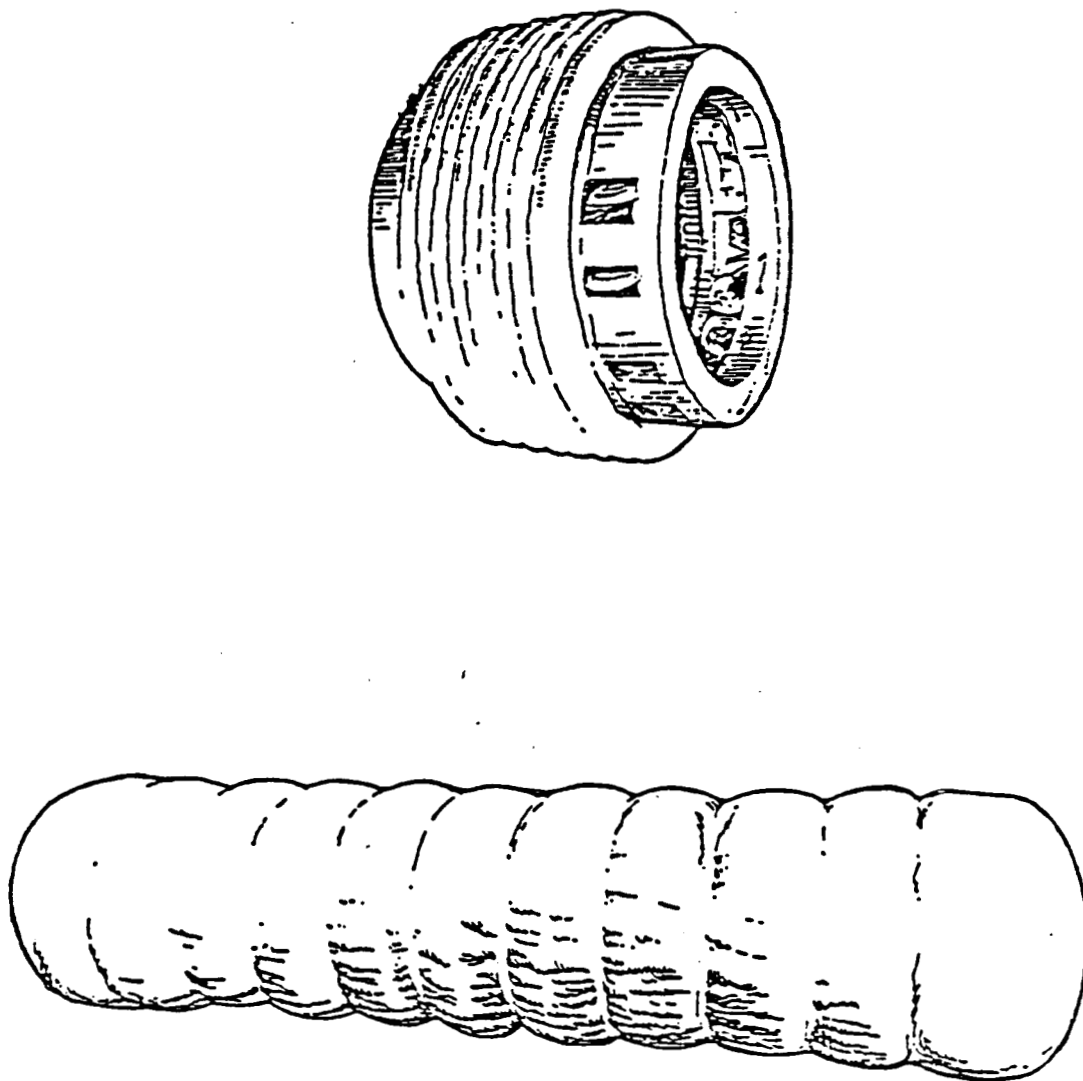


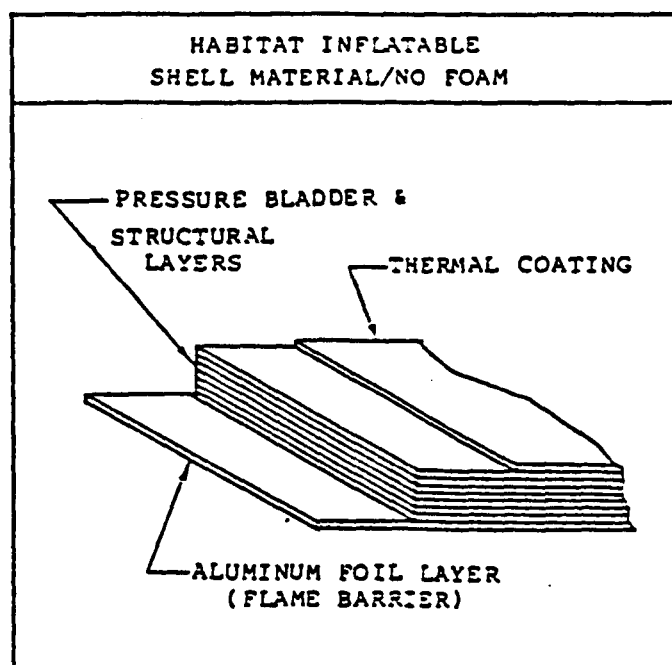
FIGURE 3    SPACELAB TRANSFER TUNNEL

#### C. Nomex/Viton B-50 Flexible Construction (Figure 4)

GAC qualified a flexible fabric consisting of Nomex unidirectional cloth coated with Viton B-50 elastomer for use as an expandable tunnel to connect the Shuttle crew cabin to the Spacelab module. This material also has potential applications for inflatable habitats.

- o An even number of multiple layers of Nomex/Viton B-50 qualified material are to be laminated together until desired strength is obtained.
- o A flexible cable can serve as a bead to assure structural integrity during deployment and fully inflated operational conditions. (This approach has been effectively used to eliminate pressure leaks.)
- o A film can be attached to the rigid surface inboard of the bead section to eliminate a potential leakage path of the bead. (Pressure inside the habitat can aid the film in its sealing action.)
- o Possible requirements for a foam micrometeoroid layer should be determined by tests.
- o A flame barrier (possibly comprised of an aluminum foil layer) may or may not be required in combination with the Nomex/Viton B-50 material.

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NOMEX/VITON PROPERTIES (PER PLY AVERAGE VALUES)	
Strip Tensile Strength	1,074 lb/inch
Weight, after cure	46.13 oz/yd <sup>2</sup>
Thickness, after cure	0.040 inch
Peel Adhesion, after cure	29.7 lb/inch

DETAIL WEIGHTS OF INFLATABLE MATERIAL		
CONSTRUCTION	GM/CM <sup>2</sup>	OZ/YARD <sup>2</sup>
Aluminum Foil Layer	0.002	0.590
Adhesive	0.005	1.474
Structural Layers	1.370	405
Adhesive	0.005	1.474
Thermal Coating	0.031	9.139
Total	1.42	418

FIGURE 4 NOMEX/VITON B-50 FLEXIBLE CONSTRUCTION



#### D. Kevlar 29 Flexible Construction (Figure 5)

Kevlar 29, a textile fiber, offers an attractive alternative to Nomex/Viton for expandable tunnel and habitable module construction. The material is stronger than stainless steel, comparable in weight to nylon and dacron, and has higher temperature limits than Nomex. GAC proposes a 4-layer laminated construction approach:

- o Unstressed inner layers of nylon fabric, capran film, EPT closed cell foam and aluminum foil can comprise a pressure bladder.
- o Kevlar 29 can be used for a structural layer to carry transmitted pressure loads. (See Note)
- o Polyurethane foam laminated to a layer of nylon fabric can provide a micrometeoroid barrier to prevent penetration of the bladder by high velocity particles.
- o An outer cover made of nylon fabric laminated to layers of capran film can provide a micrometeoroid bumper that also serves as a cover encapsulating the system surface and thermal control.
- o Alternatively, an outer cover comprised of multiple layered aluminized mylar sheets separated by fabric netting might be used for passive thermal control in the space environment.

Note: Kevlar 49 is an improved Kevlar material and would be used in lieu of Kevlar 29.

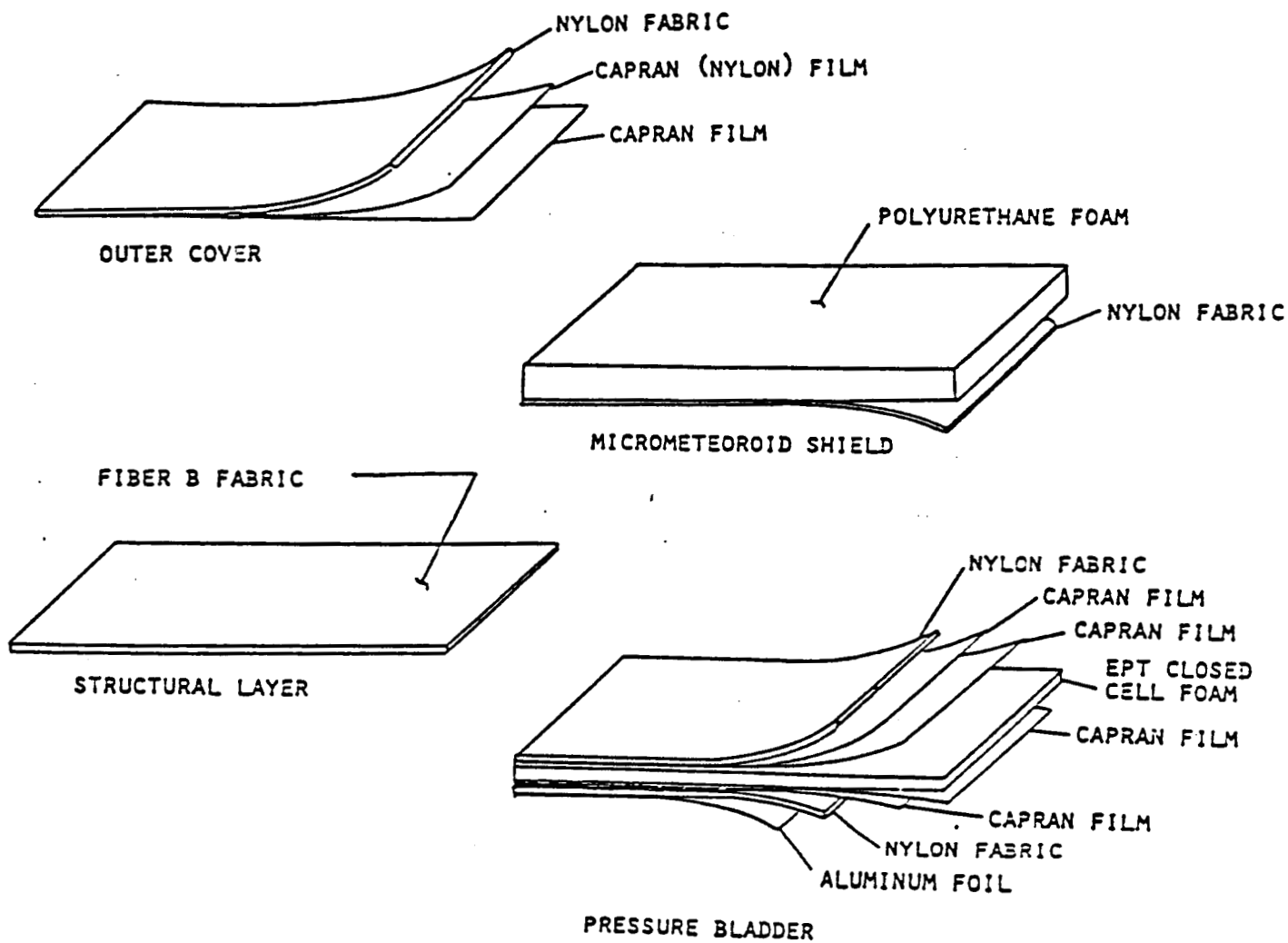


FIGURE 5 KEVLAR 29 FLEXIBLE CONSTRUCTION

## **Appendix #2**

### **Task #2**

#### **HOST Power Requirements**

**H.O.S.T. Power Requirements****• Actuator**

The H.O.S.T. actuator selected for this analysis has the following characteristics:

59.0274 in. length closed

93.5133 in. length extended

34.4859 in. extension length

The angle between the plane of the table and the actuator:

10 deg. closed

51.565 deg. extended

The force capability of the actuator is 1000 lbf along the actuator.

The actual force applied normal to the tables direction of motion is

173.6 lbf at 10 deg.

783.3 lbf at 51.6 deg.

The power required for the actuator and its speed of operation is a function of the load applied to the table. If we allow a table force greater than that at 10 deg. to be applied to the table then it will stall.

Therefore the maximum force per actuator is 173.6 lbf or 1041.6 lbf for the table. This results in the following forces on the actuators

1000 lbf at 10 deg.

221.7 lbf at 51.6 deg.

The force varies as the inverse of the sine of the angle.

The following functions represent the velocity of the actuator and the current requirements for the actuator as a function of load

$L$  = axial load on actuator (lbf)

$i$  = motor current of actuator (amps)

$v$  = actuator axial velocity (in/sec)

$$i = 3.5 + 0.0035 * L \quad **$$

$$v = 0.6 - 0.0002 * L \quad **$$

[\*\* Derived from Warner Electric , Electrak 10 Data sheet 7/86 ]

These functions were used to determine the overall power requirements for the actuators.

**• Power Controller**

The power control function will be performed by individual power controllers on each actuator and connected to a microprocessor controlled interface on each table. Commands will be sent from the command computer in the capsule to the tables via a data buss. The controllers will be designed around an H configuration of Power Metal Oxide Semiconductor Field Effect Transistors (MOSFET). The average efficiency of these controllers is 92.5% and the current requirements for the circuitry is 100 milliamps per motor. At 24 volts supply voltage the power required per motor is 2.4 watts.

- **Power Buss**

For simplicity the power buss is assumed to be 10% longer than the distance between tables , 55 meter or 180.4 ft for the total extension. The buss was assumed to consist of the equivalent of 6 gauge silver coated copper wire. It is assumed that the tables are connected in parallel to the buss and only have the losses associated with the distance of the table from the station. ie. the first table's losses are due to 14.4 ft of cable while the last table's losses are due to 361 ft of cable.

- **Power Requirements**

The power required to fully extend an actuator was computed using the functions described above. Next the power controller efficiency was applied and then the controller power requirements. This resulted in a total power requirement for each actuator.

amps	watts	
4.63	111.21	actuator
0.38	9.02	controller efficiency losses
0.10	2.40	controller
5.11	122.63	total power per actuator

The time required for full extension of an actuator is 64.33 sec. We will assume that only one table at a time is powered. Therefore the time required for a full extension or retraction is 1608.25 sec or 26.8 min.

The total power losses in the power buss is 1848.06 watts of full extension or retraction and varies from 5.69 watts loss at the first table to 142.16 watts at the last table with an average loss of 73.92 watts per table.

The total power required for the extension or retraction of a single table is 735.78 watts and adding the maximum loss for a table of 142.16 watts, the maximum power requirement at any instant is 877.94 watts or a current of 36.6 amps .

If we multiply the power required for a single table times its operational time we get the energy requirements for a full extension or retraction of H.O.S.T.

$$\begin{aligned}
 877.94 \text{ watts} * 64.33 \text{ sec} &= 56477.88 \text{ watt-sec} \\
 56477.88 \text{ watt-sec} * 25 \text{ tables} &= 1411947.00 \text{ watt-sec} \\
 1411947.00 \text{ watt-sec} / 3600 \text{ sec/hr} &= 392.21 \text{ watt-hr}
 \end{aligned}$$

**Appendix #3**

**Task #3**

**Assessment of Existing EVA Suit/MMU ECLSS for HOST**

## POD - ECLSS

### ECLSS General Description

1.0 The POD Environmental Control and Life Support System (ECLSS) provides for a single individual for up to 8 hours. The pod ECLSS must be replenished between operations. A 16 hour contingency backup system has been provided. The system maintains the pod cabin atmosphere's temperature, humidity, pressure and provides control of atmospheric composition. The pod ECLSS also provides air cooling of the internal avionics and the detection and suppression of fires.

To minimize cost, the pod ECLSS has been designed to be compatible and common with the space station ECLSS where practical or has utilized off the shelf hardware from either the Spacelab/Shuttle programs or from the EVA program. The baseline ECLSS is shown in Figure 1. Sizing data for the ECLSS hardware and Thermal Control Subsystem is provided in the back of this section.

The pod ECLSS is composed of 5 subsystems including the Temperature and Humidity Control (THC), Atmosphere Control and Supply (ASC), Atmosphere Revitalization (AR), Fire Detection and Suppression (FDS), and Water Recovery and Management (WRM). Unlike the station ECLSS, only temporary urine collection and no EVA support facilities are provided. Summaries of the ECLSS mass, volume and power are shown in Figure 2.

#### 1.1 Temperature and Humidity Control (THC)

The THC subsystem provides for the control of the pod temperature, humidity, and ventilation and provides air cooling for the internal avionics. A conductive mounting structure to mount a thermos for the crew drink is also provided. The pod cabin air temperature will be selectable and controlled within +/- 2 deg F of the set point.

#### 1.2 Atmosphere Control and Supply (ASC)

The pod ACS subsystem provides total pressure control within the pod housing. This subsystem includes the oxygen supply subsystem and the vent and relief assemblies. No nitrogen supply is provided due to the limited time the pod is occupied. Leakage makeup is from the oxygen supply only.

### 1.3 Atmosphere Revitalization

The AR subsystem provides for the removal and collection of metabolic carbon dioxide. The baseline system is a non-regenerable LiOH collection system. The baseline is derived from technology that is available off the shelf but alternate designs are presented which will allow the collection of the Carbon Dioxide for recovery in the Space Station. Trace contaminants are controlled by charcoal beds. No trace contamination monitoring is provided. The systems is designed to allow the entire pod atmosphere to be replaced during periods attached to the Station.

### 1.4 Fire Detection and Suppression (FDS)

The FDS subsystem consists of fixed hardware to detect and suppress fires in the avionics subsystems. A portable fire suppression device is also provided. A fire mask is provided within easy reach of the crew to allow the crew to breath after the halogen has been released until the pod can return to the station.

### 1.5 Water Recovery and Management (WRM)

The pod WRM provides for the collection of urine and condensate during the 8 hour operations for recovery in the station. No water quality monitoring is provided. Potable water is obtained from the station supplies and is stored in portable thermos for use by the crew.



# POD ECLSS BASELINE

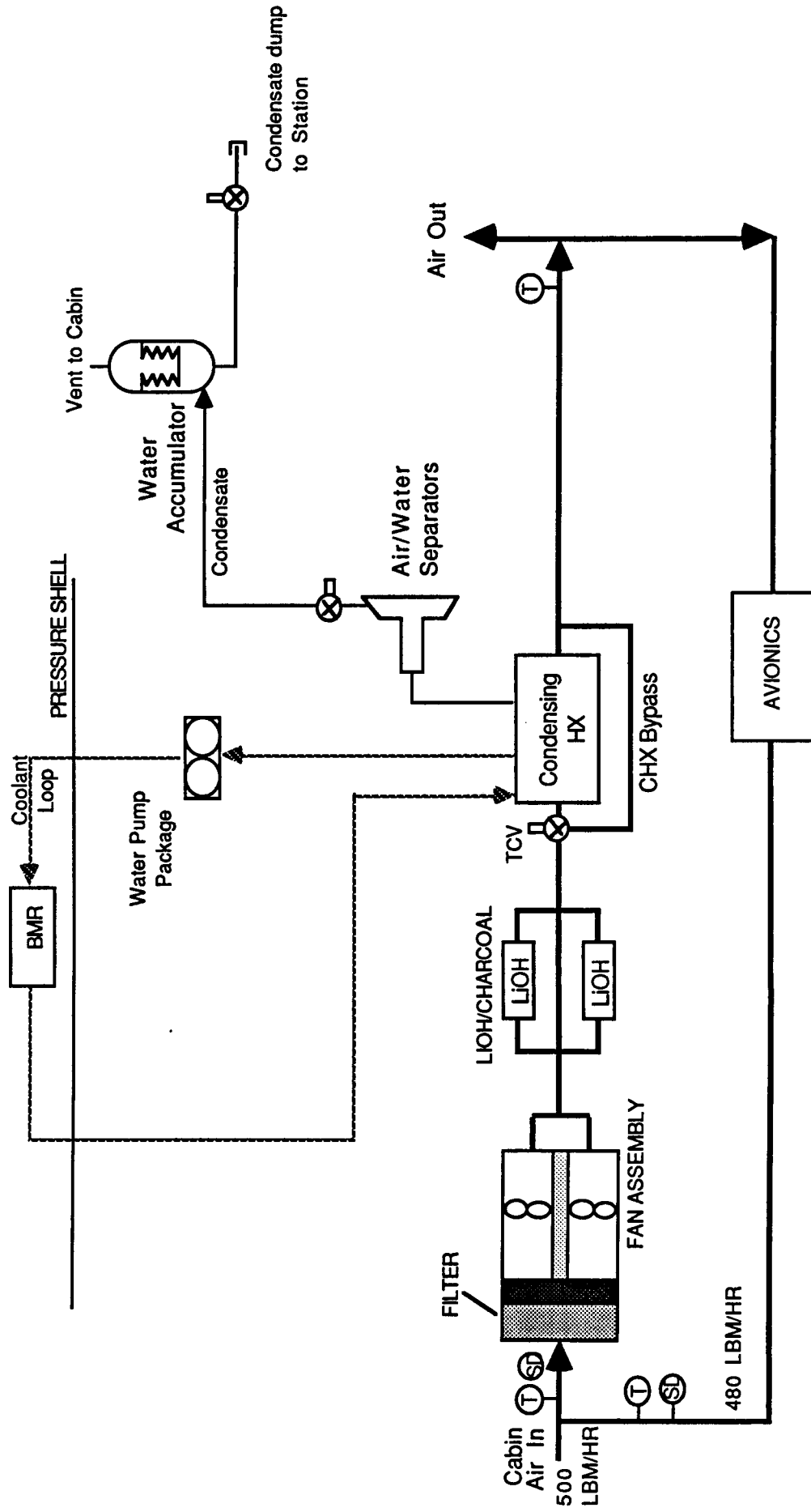


FIGURE 1

## 2.1 System Design Loads

The pod ECLSS is sized for the Design loads and respirable Atmosphere requirements shown below:

General		
Number of crew	1	
Resupply interval	8 hours	
THC		
Sweat and respiration water	.17	1bm/man-hr
Metabolic and Sensible Heat	467.0	Btu/man-hr
Hygiene Latent water	0.04	1bm/man-hr
ACS		
Atmosphere Leakage	0.05	1bm/day
Air volume	221	ft**3
AR		
Metabolic Oxygen	1.84	1bm/man-day
Metabolic Carbon Dioxide	2.20	1bm/man-day
FDS		
TBD		
WRM		
Potable water (drink)	1.0	1bm/8 hr
Metabolic water	0.03	1bm/8 hr
Urine water	3.31	1bm/8 hr

### Pod Respirable Atmosphere Requirements

Parameter	Units	Operational	Emergency
ppCO2	mmHg	3.0	12
Temperature	deg F	65-80	60-85
Dew point	deg F	40-60	35-70
Ventilation	ft/min	15-40	10-200
Total Pressure	psia	14.7+/- TBD	14.7 +/-
ppO2	psia	2.83-3.35	2.3-3.45

SYSTEM MASS, VOLUME AND POWER SUMMARIES FOR BASELINE ECLSS

Figure 2

	COMPONENT			SYSTEM TOTAL		
	WEIGHT LBM	VOLUME FT3	POWER WATTS	WEIGHT LBM	VOLUME FT3	POWER WATTS
FAN ASSEMBLY						
CABIN/AVIOICS FAN	43.00	NA	122.00	43.00	NA	122.00
CABIN FAN ASSEMBLY	21.00	1.80	0.00	21.00	1.80	0.00
CO2/HUMIDITY CONTROL						
ASSEMBLY	25.00	4.20	5.00	25.00	4.20	5.00
CARTRIDGE	6.50	NA	0.00	19.50	NA	0.00
CONDENSING HX	20.00	1.70	0.00	20.00	1.70	0.00
WATER SEPARATOR	14.00	0.80	20.00	14.00	0.80	20.00
CONDENSATE ACCUMULATOR	10.00	0.30	0.00	10.00	0.30	0.00
PLUMBING + DUCTING (20%)	27.90	1.76	0.00	30.50	1.76	
ATMOSPHERE SUPPLY AND CONTROL						
OXYGEN TANK	6.00	0.50	0.00	6.00	0.50	0.00
O2 VALVE and ELECTRONICS	2.00	0.01	15.00	2.00	0.01	15.00
PRESSURE RELIEF	2.00	0.01	5.00	2.00	0.01	5.00
PLUMBING (15% TOTAL)	1.50	0.08		1.50	0.08	
WATER/URINE RECOVERY						
URINE TANK	20.00	0.10	0.00	20.00	0.10	0.00
THERMOS (POTABLE DRINK)	2.00	0.02	0.00	2.00	0.02	0.00
ECLSS TOTALS	200.90	11.28	167.00	216.50	11.28	167.00
POD THERMAL CONTROL SYSTEM						
WATER PUMP PK	45.00	1.30	66.00	45.00	1.30	66.00
BODY MOUNTED RADIATOR	43.00	33.00		43.00	33.00	
PLUMBING (20%)	17.60	6.86		17.60	6.86	
THERMAL CONTROL TOTAL	105.60	41.16	66.00	105.60	41.16	66.00
TOTAL	306.50	52.44	233.00	322.10	52.44	233.00

## Pod Temperature Control System

### 3.1 Pod Temperature Control System (TCS)

The pod TCS is composed of an Active Thermal Control system (ATCS) and a Passive Thermal Control System (PTCS). The ATCS collects, transports and rejects waste heat from the pod. The ATCS has been designed to be compatible and common with the station where practical. The PTCS is designed to isolate the pod internal atmosphere from the external environment while minimizing the supplemental heating requirements.

#### 3.1.1 Active Thermal Control Subsystem (ATCS)

The baseline ATCS consists a pumped water loop which rejects the heat through a large Body Mounted Radiator (BMR). The BMR is mounted on a connecting structure and utilizes hardware derived from the Space Station program. An alternate design is provided which utilizes a vapor compression cycle heat pump to reduce radiator area. Figure 3 presents the baseline system.

#### 3.1.2 Passive Thermal Control Subsystem (PTCS)

The pod PTCS uses station developed construction techniques and consists of high quality insulation and surface coatings to minimize the heat gain or loss from the orbital environment. The baseline system uses MultiLayer Insulation (MLI) under a meteoroid shield.

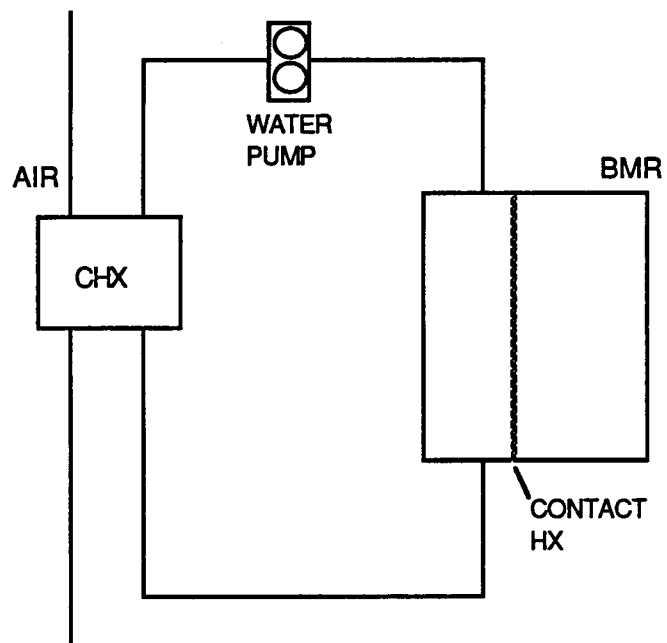
### 3.2 Alternate Heat Rejection Subsystems

The heat exchanger portion of the baseline system is shown in Figure 3. Its advantage is the use of compatible space station hardware and has low power consumption. The drawback is that it requires a large radiator area. Since the POD does not have sufficient area for the baseline radiator, a connecting structure is included between the POD and truss to mount the radiators.

A slight decrease in radiator area can be obtained using Shuttle derived hardware (freon loop with single phase radiator, figure 4). However, the power requirement increases and does not provide radiator reduction. A third alternative (Figure 5) would reduce the radiator area requirement by approximately 70% (140 to 40 ft\*\*2) which might eliminate the requirement for any extra POD truss structure for radiator mounting. This approach provides a more flexible design and reduced system weight, but with a more complex and new component development as well as higher power requirements.

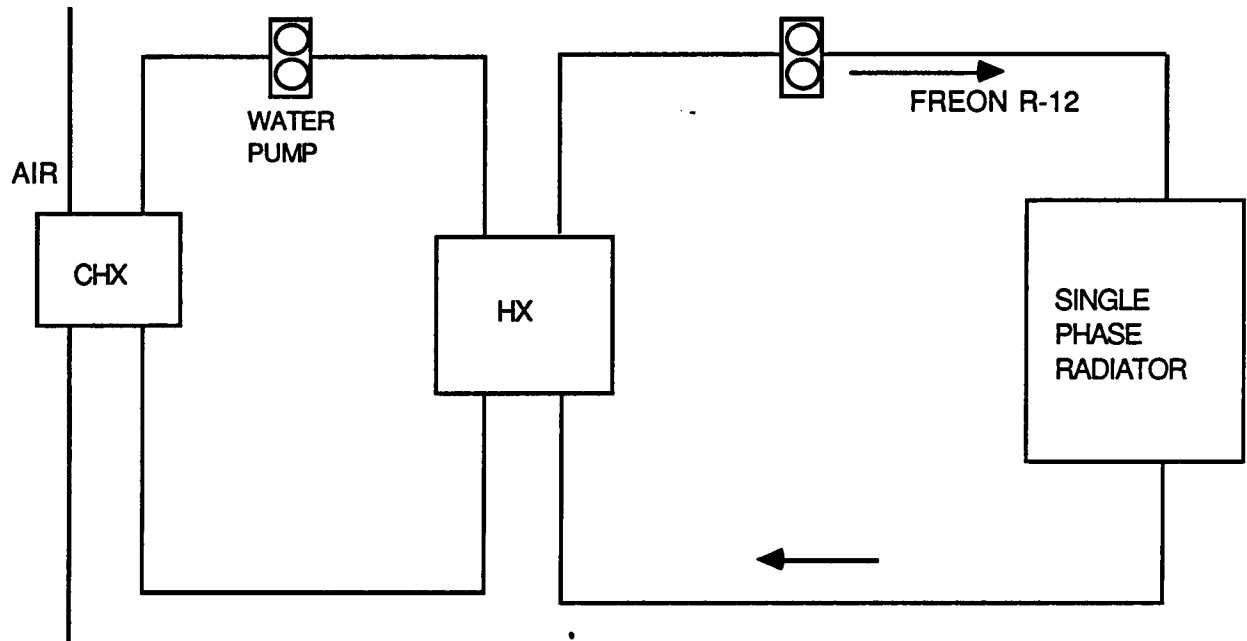
#### 4.1 Alternate POD Lower Pressure System

A brief examination was made of a low pressure system for the POD (Figure 6), but the additional hardware, Oxygen resupply and operational impacts led to selection of the baseline system that uses the standard 14.7 PSIA Space Station pressure.



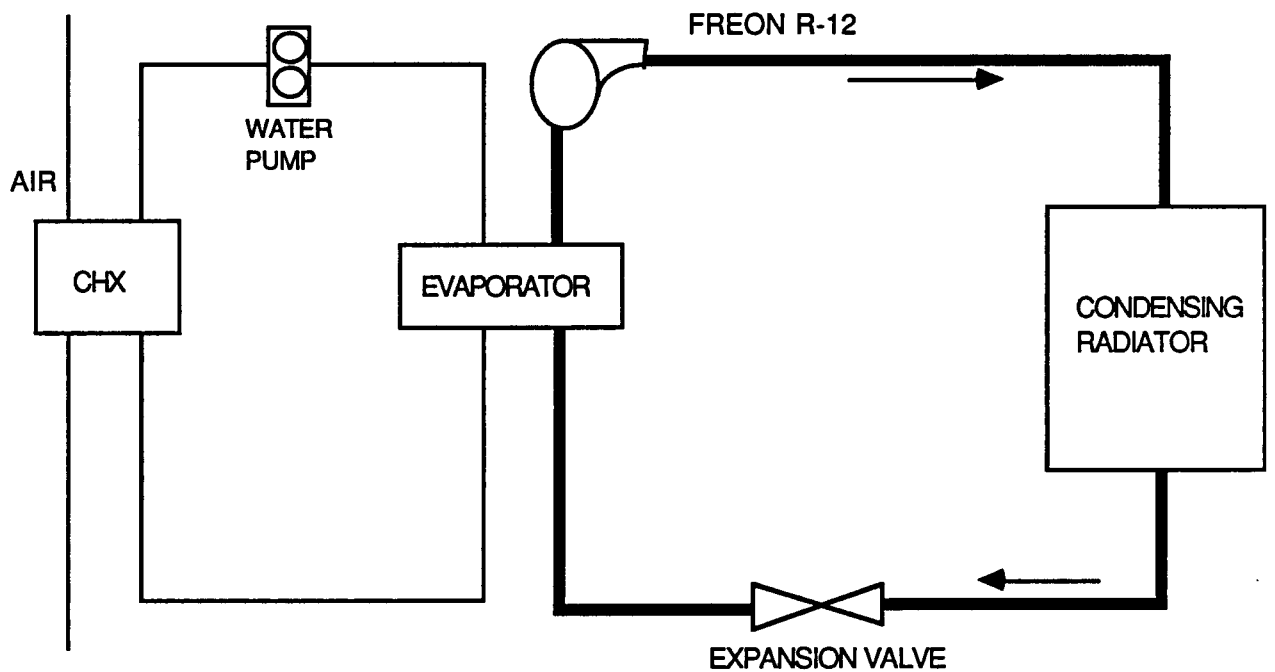
- USES SPACE STATION HARDWARE
- LOWER POWER CONSUMPTION (66 WATTS)
- REQUIRES LARGE RADIATOR AREA (140 FT\*\*2)

FIGURE 3



- USES SHUTTLE DERIVED HARDWARE
- REQUIRES MORE POWER THEN TWO PHASE SYSTEM
- LARGE RADIATOR AREA (130 FT\*\*2)

FIGURE 4



- SMALLER RADIATOR AREA (40 FT\*\*2)
- HIGHER POWER REQUIREMENTS (66 + 200 WATTS)
- MORE COMPLEX
- MORE FLEXIBLE DESIGN

FIGURE 5

## DELTA FOR LOW PRESSURE SYSTEM

### ADDITIONAL ECLSS HARDWARE REQUIRED

- PUMP: USED TO LOWER POD PRESSURE  
BY PUMPING AIR INTO STATION (NO VENT)
- BASIC HARDWARE IDENTICAL

### RESUPPLY

- REQUIRES ADDITIONAL OXYGEN (POD ATMOSPHERE 30 TO 40 % OXYGEN)

### OPERATIONS

- PHYSIOLOGICAL
  - EFFECTS OF REPEATED DECOMPRESSIONS ON WORK PERFORMANCE IS UNKNOWN
  - REPEATED DECOMPRESSIONS MAY LEAD TO INCREASED RISK OF DECOMPRESSION SICKNESS
- DELAYS START OF SESSION FOR PUMP DOWN AND ATMOSPHERE CONDITIONING
- PREBREATHING TIME CAN VARY FROM 0 TO 8 HOURS DEPENDING ON TISSUE NITROGEN PARTIAL PRESSURE AND POD TOTAL PRESSURE
- FLAMMABILITY INCREASES WITH O<sub>2</sub> PARTIAL PRESSURE INCREASE
- LOWER EVA SUIT PRESSURES ARE USED TO INCREASE MOBILITY (GLOVES)

FIGURE 6



## Advanced ECLSS Options

A considerable amount of R & D work is now going on for the ECLS systems for both the station and the EVA suit. The work includes replacing the expendable LiOH system with a regenerative systems. This will allow the recovery of the carbon dioxide for processing by the station systems. The advanced ECLSS concepts were not included in the baseline because they are not available at present. In fact there is a considerable amount of competition going on between two systems and neither appears to a clear winner. Two possible approaches are shown in Figures 7 and 8 respectively. The first approach (Figure 7) uses a solid amine, in this case WA-21, to absorb the carbon dioxide. The amine will absorb water vapor in the process thereby eliminating the condensing heat exchanger. The regeneration hardware would be on board the station. The diagram shows a removable Carbon Dioxide/Humidity absorber which would be changed out between excursions. The crew time required would be similar to that required by the LiOH system.

Figure 8 shows an Electrochemical approach in which the carbon dioxide is absorbed into a aqueous alkaline absorbent. Moisture is absorbed into the absorbent due the partial pressure difference between the solution and the cabin air. The figure shows Quick Disconnects (QD) which are used to replace the alkaline absorbent between excursions.

The advanced systems are compared for mass volume and power requirements in the attached table. The new systems reduce the complexity of the systems somewhat and do allow the recovery of the metabolic products, but the baseline system appears to be competitive when considering the power penalties for the regeneration. Both of these systems are now being bread boarded for the EVA suits and development is continuing. The units will perform as required and the final choice of the pod ECLSS will probably be driven by the availability of these units.

# POD ECLSS SOLID AMINE

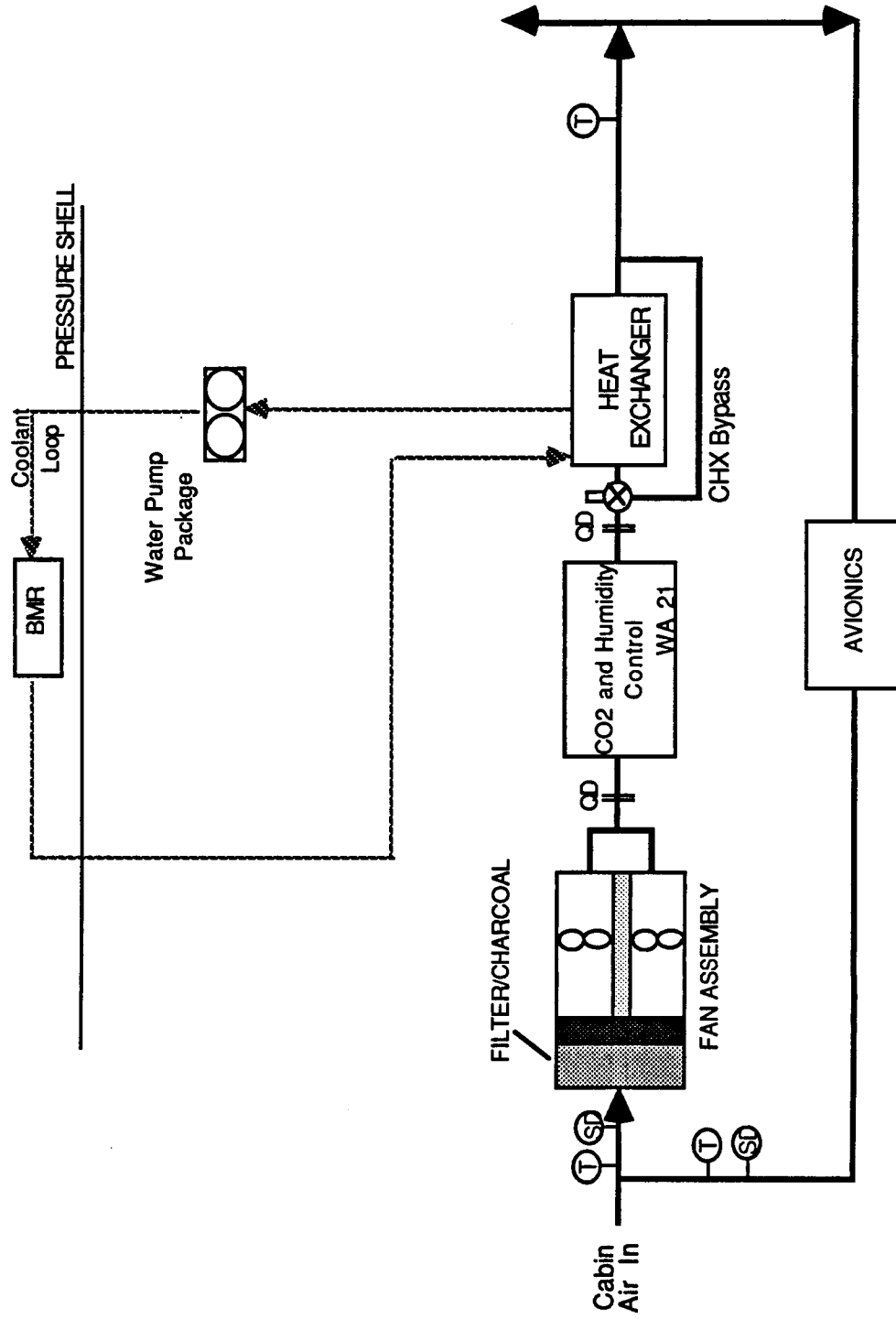


FIGURE 7

# POD ECLSS ELECTROCHEMICAL

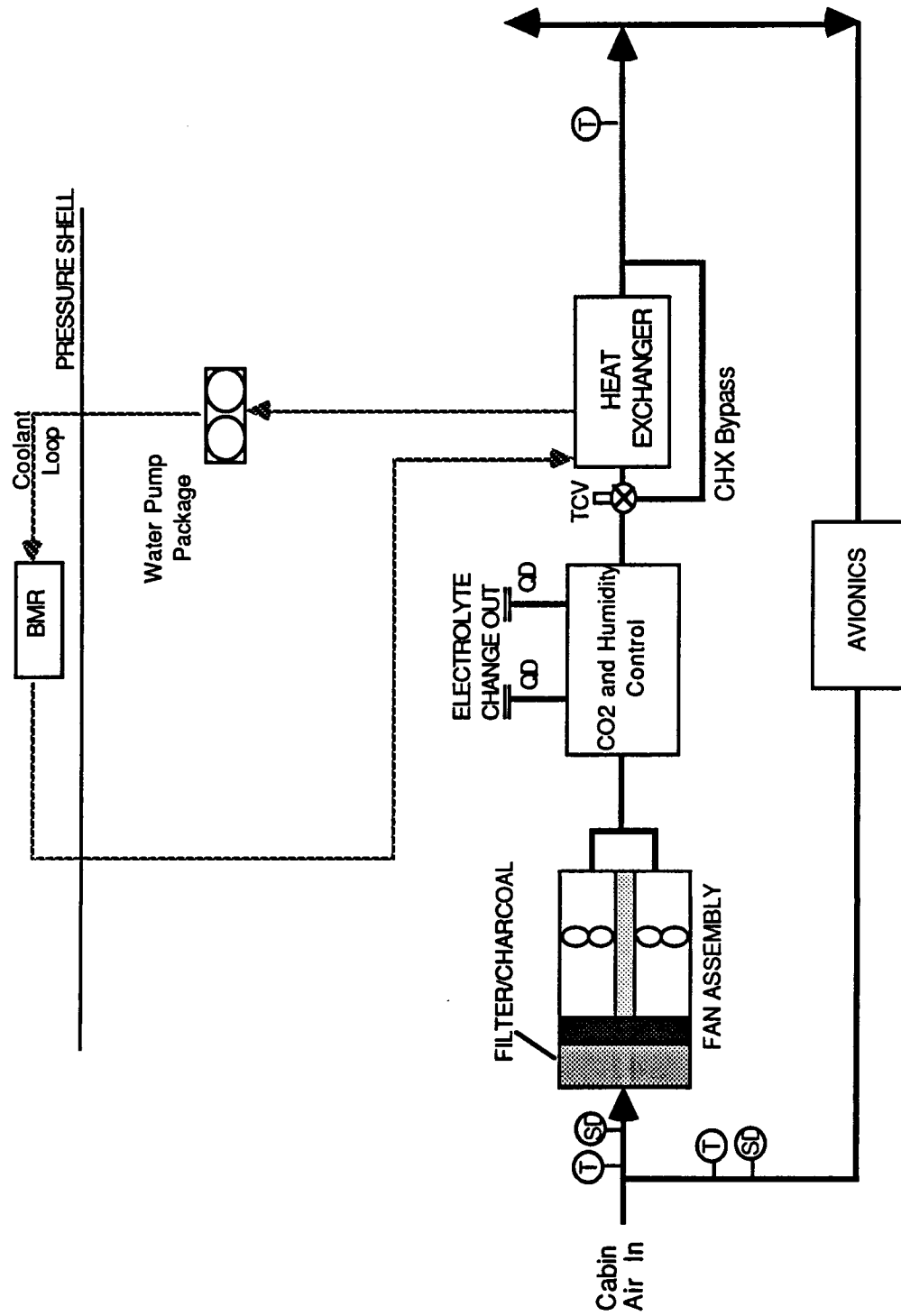


FIGURE 8

# ADVANCED ECLSS CONCEPT SUMMARIES

	LIQH	SOLID AMINE	ELECTROCHEMICAL
WEIGHT (LBM)	6.50	73.00	83.00
VOLUME (FT**3)	0.17	1.10	1.00
POWER (WATTS)	3.50	3.50	1.50
RESUPPLY WEIGHT (LBM)	195.00	22.00	10.00
VOLUME (FT**3)	5.10	0.33	0.20
REGENERATION			
WEIGHT (LBM)	0.00	70.00	93.00
VOLUME (FT**3)	0.00	2.00	3.10
POWER (WATTS)	0.00	1200.00	1280.00
CREW TIME (MINUTES)			
REPLACE	5.00	5.00	5.00
REGENERATE	0.00	3.00	3.00

## ECLSS Hardware Sizing and Performance

### 1.0 Hardware Sizing and Design Loads

Hardware sizing and performance are based on Spacelab data and has been derived from Spacelab assemblies where possible. In some cases the hardware is derived from Shuttle EVA equipment. Most components are off the shelf items. The cabin fan and Carbon Dioxide control assemblies will be scaled down from Shuttle/Spacelab hardware.

#### Design Loads For Thermal Control Systems

Component	Watts
-----	
Avionics	700
ECLS	240
Environmental Gain (Loss)	100 (-150)
Metabolic	137

## 2.0 Cabin Fan

A redundant fan assembly is required. Loss of cabin temperature control and avionics thermal control could produce a life threatening situation. The fan is scaled between the IMU fan and the Spacelab Avionics fan. The volume is included in the Cabin Fan assembly.

### Fan Characteristics

Flow	550 lbm/hr
Power	122 watts max
Weight	43.01bm

## 2.1 Cabin Fan Assembly

Cabin fan assembly includes mounting provisions for the air filter and Carbon Dioxide sensor. Provisions for a redundant fan assembly is assumed and weight includes check valves.

Power	(fan)
Weight	21 lbm
Volume	1.8 ft**3

## 3.0 Carbon Dioxide Control Assembly

The Carbon Dioxide Control Assembly is Spacelab derived and includes provisions for 2 installed LiOH cartridges of which one is the backup for contingency operations. An additional on board spare provides the 16 hour contingency. The assembly includes the temperature control valve.

Power (controllers)	5 watts
Weight	25 lb
Volume	4.2 ft**3

## 4.0 Carbon Dioxide Absorber Elements

One unit is replaced for every 8 hours of operation. Two spare units are in the FOD for contingency. The cartridges contain LiOH plus charcoal and potassium permanganate to control trace contaminant levels in the FOD.

Weight	6.5 lb
Volume	1.17 ft**3

#### 5.0 Condensing Heat Exchanger

Spacelab/Shuttle derived but approximately 50% smaller.

Weight	20 lbm
Volume	1.7 ft**3

#### 6.0 Water Separator Assembly

Spacelab derived; approximately 50% smaller includes rotary separator. The EVA units are appropriate for this application but sizing data was not available for this exercise and were estimated from Spacelab data.

Power	20 watts
Weight	14 lbm
Volume	0.8 ft**3

#### 7.0 Condensate Accumulator

Aluminum outer shell with internal steel bellows; capacity is 1.0 lbs. Nitrogen pressure from the station is used to expell the condensate into station recovery systems.

Weight	10 lbs (dry)
Volume	0.3 ft**3

#### 8.0 Oxygen Supply Tank

Spherical pressure vessel with an Inconnel liner and a Kevlar/Epoxy composite overwrap liner. Tank capacity is 2 lbs which is approximately 3 times the requirement to account for ullage.

Weight	6 lbs
Volume	1.5 ft**3

#### 9.0 Urine Collection Tank

Same construction as condensate accumulator. A charcoal filter is required on the vent to cabin to prevent odor from escaping.

Weight	20 lbs
Volume	.1 ft**3

#### 10.0 Atmospheric Control and Supply Subsystem

This hardware is derived from EVA equipment which utilizes a pure oxygen supply system. The pressure relief assemblies are scaled from Spacelab/Shuttle hardware.

Power	20 watts
Weight	5 lbs
Volume	0.3 ft**3

#### 11.0 Thermal Control

Water pump package - mounted internal to FOD cabin and includes accumulator: design flow is 450 to 500 lbm/hr.

Power	66 watts
Weight	45 lb
Volume	1.3 ft**3

#### 12.0 Body Mounted Radiator

Station derived hardware with 108 w/m\*\*2 of heat rejection at 1.59 ks/m\*\*2 weight. BMR is sized for 4500 BTU/hr (1318 watts)

Area	12.2 m**2 (131.3 ft**2)
Weight	19.4 kg (43 lbs)

Space Radiator cooling with 2 phase radiator and heat pipe efficiency = 0.90



### Passive Thermal Design Option

A cold biased passive design to maintain the POD thermal environment was examined for feasibility. The results indicated that for nominal conditions with the proper optical coatings on the POD external surfaces a pure passive design is feasible. The test case used to evaluate the passive design was a sphere with absorptance of 0.20 and an emittance of 0.90. A case with higher absorptances was also examined. The POD temperature was assumed to be uniform 70 deg F. The uniform surface temperature could be obtained by placing heat pipes around the circumference of the POD. This would eliminate the large gradients which would occur if no means of distributing the heat is provided. The sink temperature or mean radiant environment was assumed to be -85 deg F. This is a practical design value which does not take into account the actual geometry of the station and orbital position. The estimated net heat gained and or lost is presented in Figure 9 for all three cases examined.

While the passive design can be developed for nominal conditions it requires heaters to maintain the environment during cold orientations. The hot conditions indicated that the environment could not be maintained since there is a net gain of heat from the environment.

There are other practical considerations to eliminating a passive thermal design including: A passive thermal control would require designing for maximum heat loads including metabolic loads (which can exceed 600 watts under high stress conditions). This forces the design to accommodate at least 1600 watts and would then require heaters to maintain the POD environment during nominal orientations and would increase the amount of heater power required during the cold orientation. A second problem is long term exposure to atomic oxygen and ultraviolet radiation which will degrade the optical properties. This will force the surfaces to be periodically regenerated. A third consideration is the thermal control of the POD during storage. During these periods the equipment will not be powered but heaters would still be required to maintain the POD equipment and to ensure condensation does not occur. Final determination of a pure passive design will require extensive analysis and will probably result in operational constraints to avoid high heat load conditions. Therefore an active design was chosen as the baseline since this allows the greatest flexibility for the POD.

# POD PASSIVE THERMAL CONTROL DESIGN

## ASSUMPTIONS

- 1) MEAN RADIANT ENVIRONMENT TEMPERATURE -85 DEG F
- 2) REALISTIC E= 0.9, ALPHA = 0.2 POLISHED ALUMINUM SURFACE  
WHITE CHEMGLAZE ALPHA= 0.2 WILL DEGRADE DUE TO  
ULTRAVIOLET / ATOMIC OXYGEN EXPOSURE
- 3) SOLAR CONSTANT 429 BTU/HR FT\*\*2 NOMINAL; 444 BTU/HR FT\*\*2 MAX
- 4) STEADY STATE
- 5) TOTAL SURFACE AREA 113 FT\*\*2

## NOMINAL

$$Q(\text{SOLAR}) = 1,420 \text{ WATTS (APLHA}=.2\text{)}$$

$$Q(\text{SOLAR}) = 2,840 \text{ WATTS (APLHA}=.4\text{)}$$

$$Q(\text{SPACE}) = -2,490 \text{ WATTS (E}=.90\text{)}$$

$$Q(\text{SPACE}) = -2,654 \text{ WATTS (E}=.96\text{)}$$

$$Q(\text{NET}) = Q(\text{SOLAR}) - Q(\text{SPACE})$$

	E=0.90	E=0.96
ALPHA		
0.20	-1,070	-1,234
0.40	350	1,860

POD DESIGN HEAT LOAD IS 1000 WATTS PASSIVE DESIGN POSSIBLE  
WITH LOW ABSORPTANCE, HIGH EMISSIVITY SURFACE

## COLD CASE

$$Q(\text{SOLAR}) = 0.0$$

$$Q(\text{SPACE}) = -2,490 \text{ (E}=.90\text{)}$$

	E=0.90
ALPHA	
0.20	-2,490
0.40	-2,490

HEAT LOSS TO SPACE CAN BE OFF-SET BY ELECTRICAL HEATERS

FIGURE 9

HOT CASE (VIEW FACTOR TO SPACE 0.50)

MAX SOLAR CONSTANT

Q(SOLAR)=1,470 (A=0.20) ; 2,940 (A=0.40)  
Q(SPACE)= 1,245 (E=0.90) ; 1,327 (E=0.96)

	Q(NET)	
	E=0.90	E=0.96
ALPHA		
0.20	225	1,695
0.40	143	1,613

TOTAL HEAT REJECTION WOULD INCLUDE EQUIPMENT AND METABOLIC

CONCLUSIONS

PASSIVE DESIGN NOT PRACTICAL

OTHER ISSUES

- TOUCH TEMPERATURES (40 TO 113 DEG F)
- THERMAL GRADIENTS ARE AN ISSURE WITHOUT HEAT PIPES
- METABOLIC LOADS CAN VARY 100%

FIGURE 9 CONTINUED

**Appendix #4**

**Task #4**

**Assessment of Crew Compatibility**

## CREW STATION ANALYSIS

### HUMAN OCCUPIED SPACE TELEOPERATOR HOST

The control pod crew station contains the controls and displays for undocking/docking the pod, directing the pod to its work area, operating the robot arms, managing the ECLSS system and the associated caution and warning displays for these systems. Foot restraints are provided at the workstation. Depending on the type of robot arm selected, some additional type of restraint such as a waist belt may also be necessary.

It is expected that hand controllers of the type chosen for the Station Remote Manipulator will be used to control pod motion. The capability for automatic positioning of the pod at the work area under computer control as well as manual operation would be included. The ability to interrupt any automatic sequence would also be provided. It is anticipated that it may be valuable to be able to freeze the lower sections of the tables from further movement while still flying the pod to a work area. If feasible, selection of these points would be provided. A backup method of driving the tables in the event of failure in the primary command system is to be examined.

The robot arm controls would be dependent on the type of arms selected. No automatic control systems are envisioned for the arms. A secondary method for releasing an arm from any grasped object or jettison of the affected end effector would be provided.

For returning to the docked position, automatic capability is planned. This would limit work site activities to those that would introduce no new structure over or adjacent to the route of return. For manual return to the docked position, either an auxiliary workstation with direct viewing or video presentation of the return route should be provided. In either case, command inputs must be coordinated with the visual presentation so that no confusion on up/down or right/left would exist.

Finally, support systems such as interior/exterior lighting, station communications, and a Space Station type caution and warning system would be parts of the POD crew operational systems.

Figure 1 shows the major activities to be performed by the crew on a typical series of HOST operations.

MISSION SCENARIO  
(Figure 1)

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SPACE STATION

- Verify electrical power status of HOST system
- Obtain fresh lithium hydroxide cannister for pod
- Translate to HOST docking station
- Verify control pod internal pressure satisfactory
- Open Space Station docking hatch

HOST CONTROL POD

- Install fresh lithium hydroxide cannister in pod ECLSS
- Turn on HOST power
- Activate pod communications system and verify
- Activate pod ECLSS system
- Verify correct operation of pod ECLSS system
- Verify correct operation of HOST control system
- Verify correct operation of HOST robot arm system
- Verify correct operation of HOST lighting system
- Close Space Station hatch
- Close pod hatch
- Depress docking station
- Perform leak check on docking station hatches
- Undock HOST from docking station
- Translate HOST to external spares storage area
- Unstow robot arms
- Select end effectors for maintenance task

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Select replacement LRU

Translate with LRU to exchange site

Exchange LRUs

Translate with bad LRU to down load storage area

Stow maintenance task end effectors

Stow robot arms

Translate HOST to structural assembly work area

Unstow robot arms

Select end effectors for assembly task and install

Perform assembly task

Stow assembly task end effectors

Stow robot arms

Perform auto translation to docking area

Dock HOST

Verify docking latches engaged

Repress docking station

Perform docking station leak check

Equalize pod and docking station

Open pod hatch

Open Space Station hatch

Deactivate pod systems

Turn off pod power

Remove spent lithium hydroxide cannister

Exit pod

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SPACE STATION

Close space station docking hatch

Transfer spent lithium hydroxide cannister to storage

Verify HOST deactivated



**Appendix # 5**

**Conceptual Design Engineering Sketch**

